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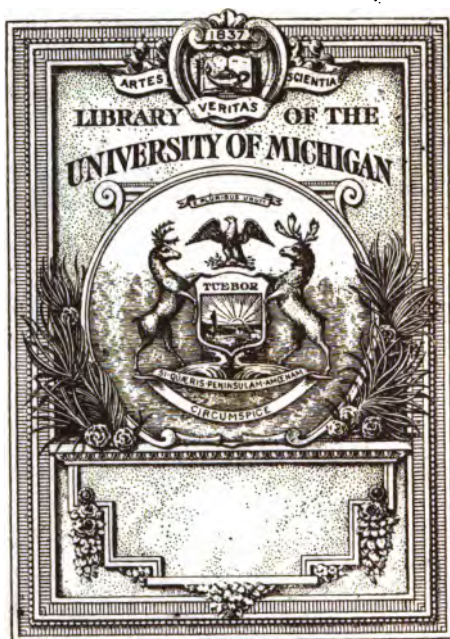
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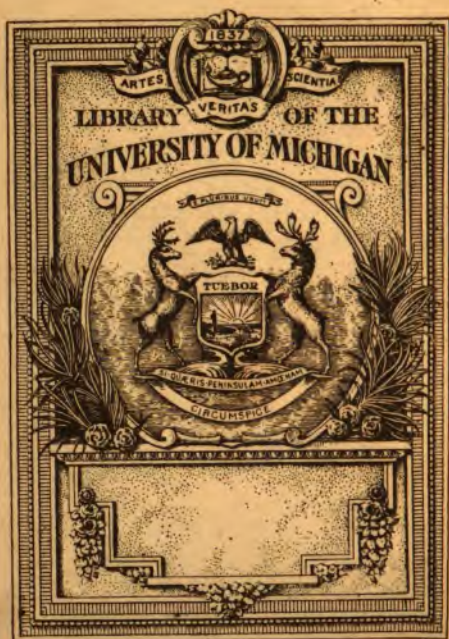


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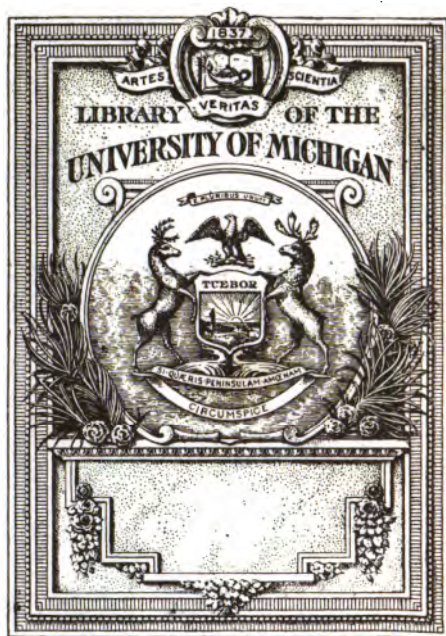
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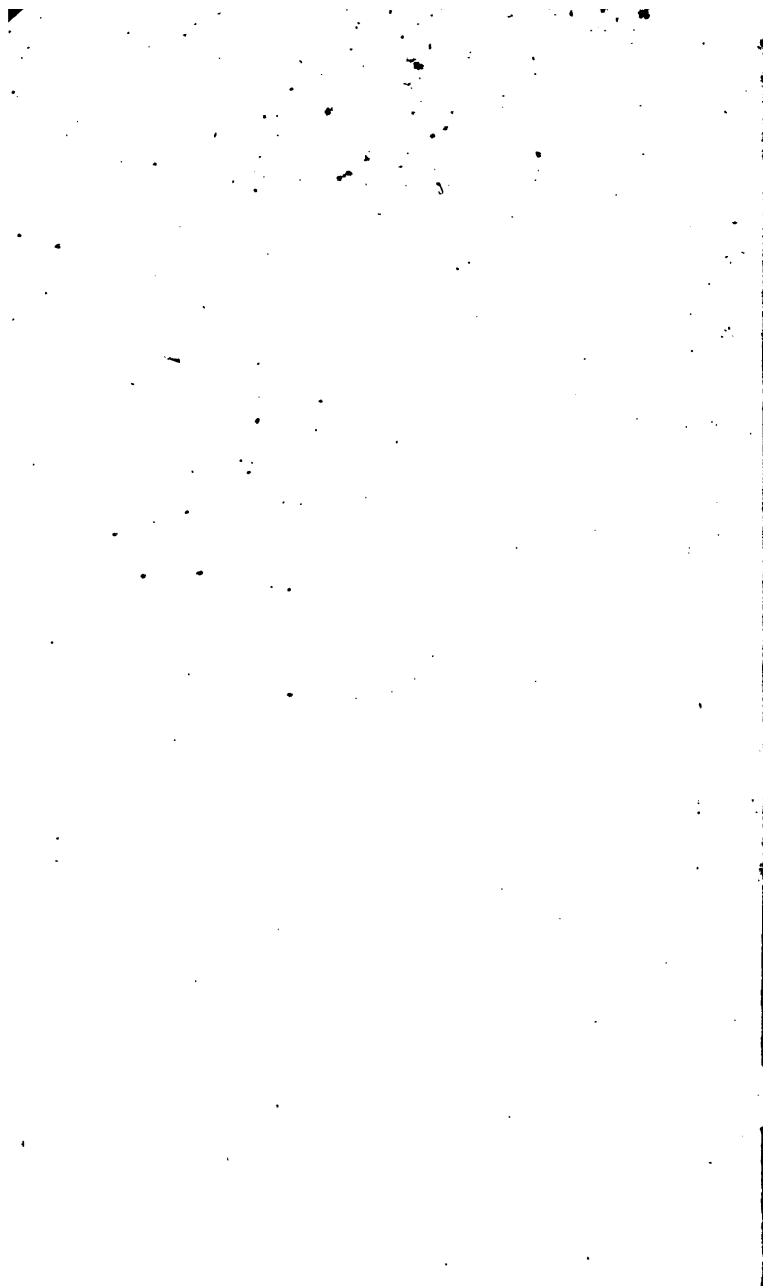


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# Handbook of Mineralogy, Blowpipe Analysis and Geometrical Crystallography

BY

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**By G. MONTAGUE BUTLER**

**A POCKET HANDBOOK OF MINERALS, 1908, 1911  
POCKET HANDBOOK OF BLOWPIPE ANALYSIS, 1910  
A MANUAL OF GEOMETRICAL CRYSTALLOGRAPHY, 1918**

**Stanbope Press**

**F. H. GILSON COMPANY  
BOSTON, U.S.A.**

# A POCKET HANDBOOK OF MINERALS

DESIGNED FOR USE IN THE FIELD OR CLASS-ROOM  
WITH  
LITTLE REFERENCE TO CHEMICAL TESTS

BY  
G. MONTAGUE BUTLER, E.M.  
PROFESSOR OF MINERALOGY AND PETROLOGY AND DEAN,  
COLLEGE OF MINES AND ENGINEERING,  
UNIVERSITY OF ARIZONA

*SECOND EDITION*  
SECOND THOUSAND  
(CORRECTED)

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## PREFACE TO FIRST EDITION.

OF works on mineralogy, there are a great number, but most of these are too cumbersome to be carried into the field and the descriptions are often so obscured with unimportant details as to make them of limited value except to specialists.

Of handbooks and tables on the subject, there are not a few, but these are mostly so condensed as to confuse rather than aid, are also often lacking in important details, and almost without exception they place the emphasis upon *chemical*, rather than physical distinctions, thus greatly limiting their value to one in the field.

This work is designed to occupy a middle ground. Although of pocket size, it aims to give *all* the details which may be needed to identify most of the minerals which mining men, students, or collectors are apt to encounter, and the emphasis is always placed upon characteristic *physical* features — little details which would ordinarily be overlooked by all but trained mineralogists, and which are often unknown to these if their training has been too closely confined to the chemical side of the science.

Nothing is herein included which may not be needed in the pursuit of the end for which the book was prepared, *i.e.*, the determination of minerals, and it is to be hoped that little has been omitted which might further that end.

That the book is usable, has been proven by the fact that scores of copies of the author's manuscript have been made by men in his classes and are now serving their purpose in the field. It is through these men, whose notes are now worn out or lost, and through many others, who

may have seen these copies, that the need for a book of this type has been made plain.

Whatever merit the book may possess will lie in the selection and arrangement of the facts presented, not in their originality. An effort has been made to offer a few *perfectly determinative tests*, rather than many details of doubtful importance.

All of these features are embodied in the course which has been given for many years by Prof. H. B. Patton in the Colorado School of Mines, and which has produced such thorough and practical results as to prove its excellence. The author is indebted to this course for his main ideas. He also desires to acknowledge indebtedness to Dana's "System of Mineralogy" and Moses and Parson's "Mineralogy, Crystallography and Blowpipe Analysis," as well as to other works, for much detailed information, and to the Foote Mineral Company, 107 North Nineteenth Street, Philadelphia, probably the best-known dealers in scientific minerals in this country, for several illustrations.

The work is not intended to be used as a manual of mineralogy but is planned to supplement lectures on the subject and to serve as a note-book on the same, thus insuring the possession of an accurate and complete set of notes. Abundant space is left for any additional matter which the owner may desire to add. It is believed, nevertheless, that the essential features are explained with sufficient care to make the book useful to collectors or mining men who have not had previous training in the subject.

Attention is invited to the following more or less original features:

1. The placing of the emphasis upon the most important characteristics by means of heavy face type. A mere glance at a page will often thus suffice to recall the appearance of a mineral, when a long description, or one in which

the important points were not thus emphasized, would fail to secure this result.

This feature is original with the author although it is used in a similar work by Mr. R. W. Richards, which did not appear until some time after the plan had been discussed with, and approved by, the publishers of this "Handbook of Minerals."

2. A systematic arrangement by paragraphs. Any feature can be at once found by looking for it in its proper place, and the whole description need not be perused to obtain the desired information.

The scheme used may be thus outlined:

Dana's Number.	Name.	Composition.	Hardness.
----------------	-------	--------------	-----------

Lustre.

Color.

Streak.

Cleavage or parting.

Tenacity and fracture.

Degree of translucency.

Miscellaneous (magnetism, taste, odor, dichroism, etc.).

Specific gravity (S. G.).

B. B. (Before Blowpipe). Here are included simple chemical tests.

Methods or habits of occurrence with a description of the crystals if the species crystallizes.

Description of varieties.

A list of minerals resembling the species under discussion, and with which it should be compared.

A short statement of the uses of the mineral.

Any species will not contain matter under all of these heads unless all are important.

3. A page following each group, containing a statement of the group characteristics and illustrations of the minerals preceding. The former will be found a considerable aid to students.

4. The provision of plenty of space for additional notes.

5. The strong binding in a form which will fit the pocket.

6. The tables in the back — a new feature which, it is hoped, may occasionally prove helpful.

It is the author's desire to make subsequent editions as complete and accurate as possible, and he will always welcome corrections or suggestions.

Some knowledge of crystallography and blowpipe analysis will be found necessary for a complete understanding of the descriptions which follow.

The names of minerals and metals are capitalized for the sake of emphasis.

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## PREFACE TO SECOND EDITION.

THE new edition differs from the first chiefly through additions made to the original text. The commoner synonyms have been appended to the scientific names of the various species and the specific gravity of each mineral included in its description. Where there is a variation of one-tenth of a unit or more, the limits are given, otherwise the average specific gravity is stated. A considerable number of additional species have been described and many varietal terms introduced. The text itself has been revised or amended as experience has shown desirable, and an effort made to correct all topographical errors of the first edition.

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## ERRATA.

- Page 27. The symbol at the lower left-hand corner of Figure 12 should be  $a:a:\infty a$ ; and that in the middle of the base of this figure should be  $a:ma:\infty a$ .
- “ 93. The word “*horizontal*” should be inserted between the words “*the*” and “*crystal*” in the 8th line from the top of the page.
- “ 109. The word “*tetragonal*” at the end of the fourth line from the top of the page should be changed to “*orthorhombic*.”

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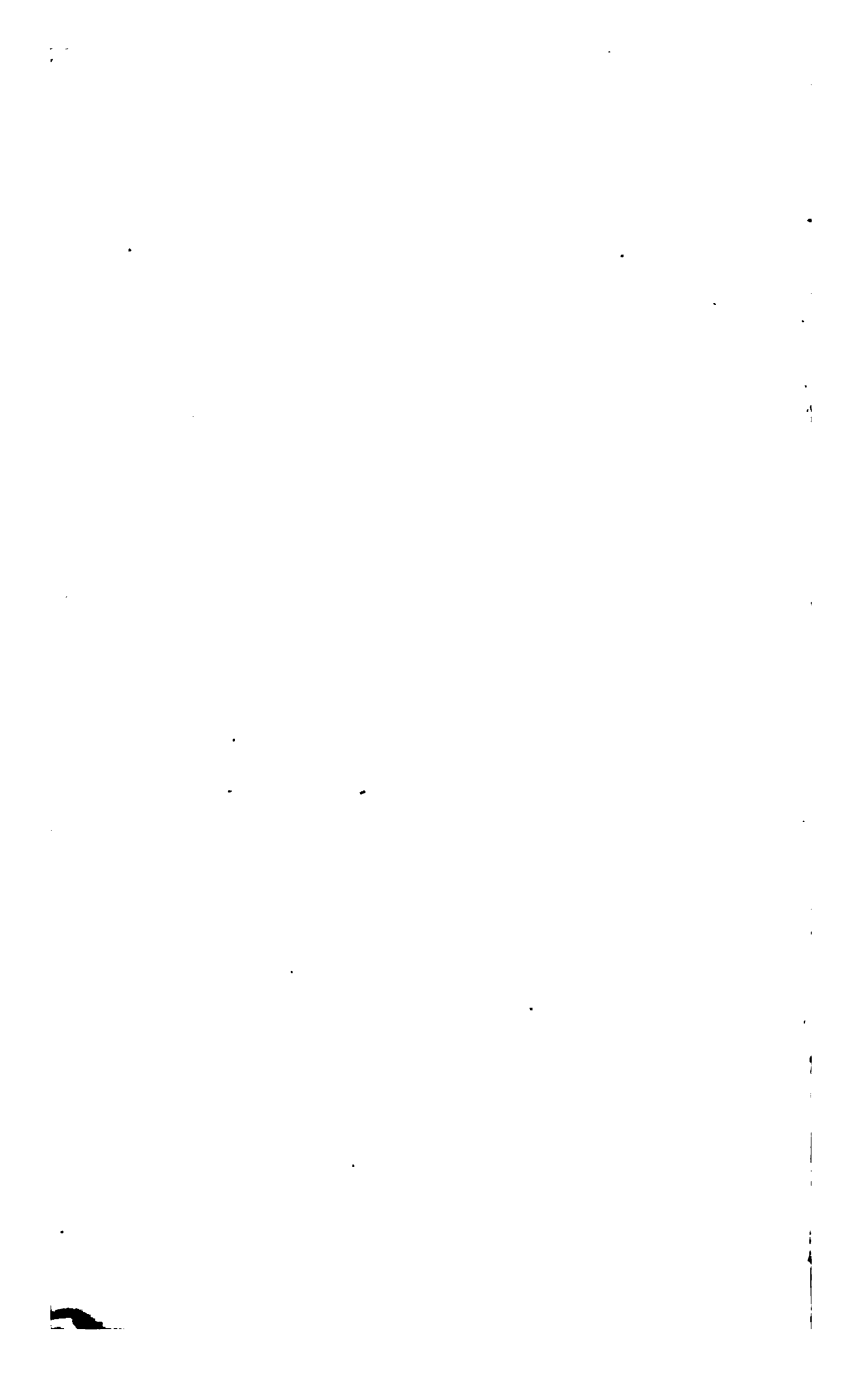
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## NATIVE ELEMENTS.

### 1. DIAMOND. C.

Hardness 10.

Lustre. — **Adamantine.**

Color. — **Colorless, white**; frequently pale tints of yellow, red, blue, green, brown; sometimes black.

Streak. — None.

Cleavage. — Perfect octahedral.

Brittle.

Transparent to opaque.

S. G. — 3.52.

B. B. — Unaltered.

Occurs crystallized in octahedrons or rounded octahedral forms and, rarely, in a cubical habit. Contact and penetration twins are common and the faces are frequently curved and striated.

The mineral also occurs granular to compact massive and in rounded forms.

#### *Varieties.*

#### **BORT.**

Opaque and dark colored; in rounded forms with a confused crystalline structure but without cleavage. It is very tough. Bort is also a trade name for fragments of crystals.

#### **CARBONADO.**

Granular to compact-massive mineral with or without cleavage.

A very beautiful and valuable gem and the opaque material furnishes the best known abrasive substance.

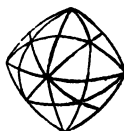


FIG. 1.  
Rounded Crystal.



FIG. 2.

**2. GRAPHITE. C.****Hardness 1-2.***(Plumbago, Black Lead.)*

Lustre. — Metallic to dull.

Color. — **Dark gray to black.**

Streak. — Dark gray.

Cleavage. — Perfect basal.

**Feels greasy and soils the fingers.**

Cleavage laminae are flexible.

Sectile.

Opaque.

S. G. — 2.09-2.23.

B. B. — Unaffected.

Occurs rarely in six-sided tabular crystals and commonly in imbedded scales and foliated-, granular-, or compact-massive. Usually found in Granites, Schists, or Limestones; occasionally in Traps.

*Varieties.*

There are several varieties of little importance which are really intermediate between Graphite and Anthracite (p. 270) in character and composition.

Compare with Molybdenite (p. 23) and Micaceous Hematite (p. 85).

Is used in the manufacture of lubricant, infusible crucibles, etc., and "lead" pencils.

**3. SULPHUR. S.**  
(Brimstone.)

**Hardness 1.5-2.5.**

Lustre. — **Resinous.**

Color. — **Various shades of yellow, orange, brown, and gray.**

Streak. — **White or yellowish.**

Fracture. — **Conchoidal to uneven.**

**Very brittle.**

Transparent to translucent.

S. G. — 2.07.

**B. B. or in a match flame — Melts and gives off SO<sub>2</sub> fumes.**

Occurs in **distinct orthorhombic crystals** and more or less porous massive. Also stalactitic, incrusting, and powdery. Often formed by volcanic action.

The habit of the crystals is often apparently sphenoidal. Brown Sulphur contains Selenium.

Compare with Orpiment (p. 19).

Is used in enormous quantities in various arts and trades.



**FIG. 3.**

## 2. GRAPHITE

(p. 970)

Luster. . .  
 Color. . .  
 Streak. . .  
 Fracture. . .  
 Fresh surfaces and  
 Fracture faces.  
 Density.  
 Crystal  
 R. H. . .  
 H. H. . .

Occurs rarely  
 mostly in impure  
 or compact ma-  
 terial (limestones).

There are some  
 very really inter-  
 (p. 970) in ch.

Compare with  
 Hematite (p. 8)

Is used in ti-  
 ble, etc., and

**ARSENIC.** As.

Hardness 3.5.

Fr. — Metallic.

Cr. — Tin-white, **tarnishing to black.**

Clk. — Tin-white.

Frage. — Perfect basal (often obscure). Granular fracture. Brittle.

Sp. — 5.63-5.73.

B. — **Volatilizes readily and entirely without fusing and gives a garlic-like odor, yielding the characteristic As sublimate on charcoal.**

Occurs usually in granular, mammillary or spherical masses which often **separate in concentric layers.**

Compare with Antimony (p. 7), Allemontite (p. 6), and Galenite (p. 27).

Arsenic or its compounds is used in alloys, in medicine, a poison, and in many arts and trades.



**9. ALLEMONTITE.**  $\text{SbAs}$ .

Hardness 3.5.

Lustre. — Metallic, sometimes very brilliant.

Color. — Tin-white, tarnishing to gray or brownish black.

Streak. — Tin-white.

Fracture. — Granular.

S. G. — 6.2.

**B. B. — Fuses easily and volatilizes with As and Sb reactions.**

Occurs usually in finely granular masses. Sometimes exhibits a curved lamellar structure.

Compare with Arsenic (p. 5), Antimony (p. 7), and Galenite (p. 27).

**10. ANTIMONY. Sb.**

Hardness 3-3.5.

Lustre. — Metallic.

Color. — Tin-white. **It does not tarnish.**

Streak. — Tin-white.

Cleavage. — **Perfect basal** and poor to good rhombohedral.

Very brittle.

S. G. — 6.68.

**B. B. — Fuses and then volatilizes**, yielding the characteristic Sb sublimate on charcoal.

Occurs in finely to coarsely granular masses and, rarely, lamellar or radiated.

Very infrequently found in rhombohedral crystals, either simple or complexly twinned.

Often associated with Cervantite (p. 79), an alteration product.

Compare with Arsenic (p. 5), Allemontite (p. 6), and Galenite (p. 27).

**TELLURIUM GROUP.**

*Members.* — Tellurium, Arsenic, Allemontite, Antimony.

*Composition.* — Semi-metals.

*Crystallization.* — Rhombohedral hemihedral hexagonal.

*Additional.* — All are soft minerals tin-white in color when freshly broken, all have a tin-white streak and a metallic lustre, and all volatilize B. B.

**GOLD GROUP.****13. GOLD.** Au.

Hardness 2.5-3.

Lustre. — Metallic.

Color. — **Golden yellow** to nearly silver-white. **Does not tarnish.**Streak. — **Yellow** to nearly white.

Fracture. — Hackly.

**Very malleable and ductile. Sectile.**S. G. — **19.3.** Impurities may lower the S. G. to as low as 15.6.

B. B. — On charcoal, fuses to a bright yellow button. Insoluble in any single acid.

Occurs in nuggets, grains and scales and in small octahedral or dodecahedral crystals which are usually badly distorted and are very apt to be united in wire-like, net-like or dendritic shapes. Crystals are often elongated parallel to the octahedral axis, resembling rhombohedrons.

*Varieties.***ELECTRUM.**

Gold alloyed with 20% or more Silver.

Other varieties are based upon and named after the impurity which may be present.

The common impurities are Ag, Cu, Bi, Rh, and Pd.

**Gold is the only yellow, malleable mineral. It is easily scratched without yielding a powder.**

The economic value and uses of Gold are well known.

See Fig. 4.

**14. SILVER.** Ag.**Hardness 2.5-3.**

Lustre. — Metallic.

Color. — **White.** Easily tarnishes to brownish gray or black and sometimes yellow, then closely resembling Gold.

Streak. — White.

Fracture. — Hackly.

**Malleable and ductile. Sectile.**S. G. — **10.5.** Impurities may make this as low as 10.1 or as high as 11.1.

B. B. — On charcoal, fuses to a white globule. Soluble in nitric or sulphuric acids and is precipitated from these in a white, curdy form by hydrochloric acid.

This precipitate turns purple when exposed to the sun.

Occurs in masses, plates, scales, and in isometric crystals which are commonly distorted and elongated to acicular forms and united in arborescent groupings, which branch at 60° parallel to the diagonals of the octahedron face.

When tarnished, Silver may resemble Gold (p. 9) or Copper (p. 11). Compare with these.

The economic value and uses of Silver are well known.

See Fig. 5.

**15. COPPER.** Cu.

Hardness 2.5-3.

Lustre. — Metallic.

Color. — **Copper-red.** Easily tarnishes bronze-green to black.

Streak. — Copper-red.

Fracture. — Hackly.

**Very malleable and ductile. Sectile.**

S. G. — 8.8-8.9.

**B. B.** — On charcoal, fuses to a copper-red mass or globule which is sometimes covered with a coating of black oxide.

Occurs in sheets, masses weighing many tons down to very small disseminated particles, and in wire-like or arborescent aggregates of much distorted isometric crystals.

Compare with Silver (p. 10), Niccolite (p. 37), and Bor-nite (p. 40).

The economic value and uses of Copper are well known.

See Fig. 6.

**16. MERCURY. Hg.****Hardness Liquid.***(Quicksilver, Hydrargyrum.)*Lustre. — **Very brilliant metallic.**

Color. — Tin-white.

Streak. — Tin-white, when solid.

Cleavage. — Perfect cubic, when solid.

S. G. — 13.6.

B. B. — Completely volatile.

Occurs in small, fluid globules in cavities in the gangue-rock.

**Mercury is the only mineral of metallic lustre that is liquid at ordinary temperatures.**

The mineral becomes solid at  $-40^{\circ}$  C., crystallizing in octahedrons.

Mercury is used in considerable quantities in some of the processes by which Gold and Silver are extracted from "free-milling" ores. It is also in demand for the manufacture of vermilion paint, in medicine, and in many arts and trades.



**GOLD GROUP.**

*Members.* — Gold, Silver, Copper and Mercury.

*Composition.* — Heavy metals.

*Crystallization.* — Holohedral isometric.

*Additional.* — All are very heavy, have a metallic lustre, are 2.5 to 3 in hardness, and are malleable (Mercury must, of course, be solid to show this).



FIG. 4. — Gold Nugget, California.



FIG. 5. — Leaf Silver, Leadville, Colorado.



FIG. 6. — Native Copper, Northern Michigan.

## PLATINUM-IRON GROUP.

**20. PLATINUM. Pt.****Hardness 4-4.5.**

Lustre. — Metallic.

Color. — **Light steel-gray.**

Streak. — Steel-gray.

Fracture. — Hackly.

**Malleable and ductile.**S. G. — **14-19** as found in nature; 22 when chemically pure.

B. B. — Infusible. Soluble only in hot aqua-regia.

The powder will usually give reactions for Fe and, often, for Cu.

Occurs as nuggets, grains, and scales, usually in alluvial deposits. Found very rarely in cubical, isometric crystals.

*Varieties.**Ordinary.*

Non-magnetic or only slightly magnetic.

*Magnetic.*

Usually contains considerable quantities of Iron or Nickel, which increases the hardness to as much as 6 and decreases the S. G. to as low as 14.

Compare with Silver (p. 10).

Platinum is now being used to a considerable extent in jewelry and for laboratory apparatus.

**25. IRON.**

Fe.

**Hardness 4-5.**

Lustre.—Metallic.

Color. — Steel-gray to black.

Streak — Gray.

Fracture. — Hackly.

**Malleable.**

S. G. — 7.3–7.8.

**Very magnetic.**

B. B. — Infusible. Soluble in acids.

Occurs very rarely native as it oxidizes very readily.

It is usually found in masses or as disseminated particles; rarely in cubo-octahedral crystals.

*Varieties.**Terrestrial.*

Originating in the earth.

*Meteoric.*

Most meteorites contain Iron, and many are composed almost entirely of this metal. Nickel, varying in amount from about five to ten per-cent, is present in all iron meteorites — siderites or holosiderites.

Compare with Silver (p. 10) and Platinum (p. 15).

Metallic Iron is too rare to be of economic importance.

**PLATINUM-IRON GROUP.**

*Members.* — Platinum, Iron.

*Composition.* — Metals.

*Crystallization.* — Holohedral isometric.

*Additional.* — Both have a hardness between 4 and 5, a metallic lustre, and are malleable.

**SULPHIDES, ETC.,**  
**OF THE**  
**SEMI-METALS AND MOLYBDENUM.**

**26. REALGAR.**  $\text{As}_2\text{S}_2$ .

Hardness 1.5-2.

Lustre. — Resinous.

Color. — **Orange-red or orange-yellow.**

Streak. — **Orange.**

Cleavage. — Fair pinacoidal.

Slightly sectile.

Translucent to transparent.

S. G. — 2.56.

B. B. — On charcoal, fuses easily. Gives S and As reactions.

Occurs usually in translucent, granular masses or compact; also in transparent, monoclinic crystals and as an incrustation.

It is usually associated with Orpiment (p. 19) to which it alters.

Compare with Orpiment (p. 19), Ruby Silvers (pp. 56-57), Cinnabar (p. 34), Cuprite (p. 80), and Crocoite (p. 263).

Seldom occurs in sufficiently large amounts or pure enough to be valuable.

## STIBNITE GROUP.

**27. ORPIMENT.**  $\text{As}_2\text{S}_3$ .

Hardness 1.5-2.

Lustre. — Resinous, to pearly on cleavage face.

Color. — **Lemon-yellow.**Streak. — **Lemon-yellow.**Cleavage. — **Perfect pinacoidal.** Cleavage laminae are flexible and often striated.

Sectile.

Translucent.

S. G. — 3.4-3.5.

B. B. — On charcoal, fuses easily. Gives S and As reactions.

Occurs in thin scales, foliated or columnar massive, and finely granular like the yolk of a hard boiled egg.

Rarely found as imperfect orthorhombic crystals.

Usually associated with Realgar (p. 18).

Compare with Sulphur (p. 3).

Seldom occurs in sufficiently large amounts or pure enough to be valuable.

**28. STIBNITE.**  $\text{Sb}_2\text{S}_3$ 

Hardness 2.

Lustre. — Bright metallic.

Color. — Light gray, tarnishing iridescent or black.

Streak. — Lead-gray.

Cleavage. — **Perfect pinacoidal, yielding blade-like strips which are usually striated or bent perpendicular to the long direction.**

Very brittle.

S. G. — 4.52–4.62.

B. B. — On charcoal, fuses very easily. Gives Sb and S reactions.

Occurs in imperfectly crystallized masses with a columnar or bladed structure or in acutely terminated, prismatic orthorhombic crystals which are usually vertically striated and are often bent. Rarely granular.

Compare with Bismuthinite (p. 21), Galenite (p. 27), Jamesonite (p. 54), Sylvanite (p. 51), and Calaverite (p. 52).

A valuable mineral since it is the chief source of Antimony and its artificial salts. Sometimes carries Gold and Silver.

Antimony is chiefly used in the manufacture of safety matches, fireworks, percussion caps, type, and other alloys.

See Fig. 8.



FIG. 7.



**29. BISMUTHINITE.**  $\text{Bi}_2\text{S}_3$ .**Hardness 2.***(Bismuth Glance.)*

Lustre. — Metallic.

Color. — Light gray to nearly white. **Yellowish or iridescent tarnish common.**

Streak. — Like color.

Cleavage. — **Fair to poor brachy pinacoidal.**

Brittle.

S. G. — 6.4–6.5.

B. B. — On charcoal, yields fumes of  $\text{SO}_2$ , and then fuses very easily with spirting, coating the coal with yellow bismuth oxide. With KI gives a bright red sublimate of bismuth iodide.

Occurs massive, as thin coatings, or in acicular to tabular orthorhombic crystals. **Often associated with Chalcopyrite or Pyrite**; sometimes with **BISMUTOSPHERITE**, a yellow or brown, earthy carbonate of bismuth.

Compare with Stibnite (p. 20), Galenite (p. 27), Jamesonite (p. 54), Sylvanite (p. 51), Calaverite (p. 52), and Tetrahedrite (p. 58).

A rare ore of Bismuth which is used in medicine, in the manufacture of easily fusible alloys that expand upon cooling, and for other purposes.

**STIBNITE GROUP.**

*Members.* — Orpiment, Stibnite, Bismuthinite.

*Composition.* — Sulphides of semi-metals.

*Crystallization.* — Orthorhombic.

*Additional.* — All are about 2 in hardness and have perfect pinacoidal cleavage.



**FIG. 8. — Stibnite, Hungary.**

**34. MOLYBDENITE.**  $\text{MoS}_2$ . Hardness 1-1.5.

Lustre. — Metallic.

Color. — Bluish or brownish lead-gray.

Streak. — **Greenish on glazed porcelain or glazed paper.**

Cleavage. — Perfect basal. **Cleavage laminae very flexible but not elastic.**

Sectile.

May feel slightly greasy but this is not so noticeable as with Graphite.

S. G. — 4.7-4.8.

B. B. — Infusible. Mo reactions on charcoal.

Occurs in granular or foliated masses or **scales** scattered through or embedded in many crystalline rocks; also in tabular hexagonal crystals.

Compare with Graphite (p. 2).

Molybdenite is the chief source of Molybdenum which is used to color pottery blue, in the manufacture of steel, paint, and dyes, and as ammonium molybdate, a valuable reagent in chemistry.

See Fig. 10.

## SULPHIDES, ETC., OF THE METALS.

### MONOSULPHIDES.

#### GALENITE GROUP.

**42. ARGENTITE.**  $\text{Ag}_2\text{S}$ . Hardness 2-2.5.  
(*Silver Glance.*)

Lustre. — Metallic.

Color. — Lead-gray to black.

Streak. — Lead-gray; shining.

**Very sectile when pure.** Uneven fracture.

S. G. — 7.2-7.36.

B. B. — Swells and fuses, yielding a button of Silver and sulphur fumes. Soluble in  $\text{HNO}_3$ .

Occurs massive, in grains, earthy, and encrusting; also in arborescent groupings of isometric crystals which are often distorted.

Frequently associated with Galenite and Sphalerite.

Compare with Chalcocite (p. 30), Hessite (p. 25), and Petzite (p. 26).

A valuable ore of Silver.

**43. HESSITE.**  $\text{Ag}_2\text{Te}$ .

Hardness 2.5-3.

Lustre. — Metallic.

Color. — Between lead and steel gray.

Streak. — Black.

Slightly sectile. Uneven fracture.

S. G. — 8.31-8.89.

**B. B. —** On charcoal, fuses to a black globule, dotted with Ag. If this be powdered and dropped into strong, boiling  $\text{H}_2\text{SO}_4$ , the acid will be colored an intense purple.

Occurs compact, fine (usually) granular, and in small, often distorted, isometric crystals.

Compare with Chalcocite (p. 30), Argentite (p. 24), and Petzite (p. 26).

A rare but valuable ore of Gold and Silver, the former often replacing the latter to a considerable extent.

**44. PETZITE.** (Ag,Au)<sub>2</sub>Te.

Hardness 2.5-3.

Lustre. — Metallic.

Color. — Steel-gray to black. Often tarnishes.

Streak. — Black.

Slightly sectile to brittle. Uneven fracture.

S. G. — 8.7-9.

B. B. — Like Hessite (p. 25) except that it yields a globule containing both Au and Ag.

Occurs fine granular to compact massive. Crystals are unknown and it is believed that the mineral may be orthorhombic and belong to the Chalcocite Group.

Compare with Chalcocite (p. 30), Argentite (p. 24), and Hessite (p. 25).

A rare but valuable ore of Gold and Silver.

45. **GALENITE.** PbS.

Hardness 3-.

(*Galena, Lead Glance.*)

Lustre. — Metallic.

Color. — Lead-gray to bluish gray. Tarnishes to black.

Streak. — Lead-gray.

Cleavage. — **Perfect cubic.** Very rarely octahedral.

**Brittle.**

S. G. — 7.4-7.6.

B. B. — Usually decrepitates and fuses easily yielding lead oxide sublimates and SO<sub>2</sub> fumes.

Occurs massive cleavable, coarse to fine granular, rarely fibrous, and in isometric (usually cubo-octahedral) crystals; sometimes in skeleton crystals or reticulated.

*Varieties.*

*Argentiferous.*

The mineral, especially the fine grained variety called **STEEL GALENA**, may contain so much Silver as to make it a valuable Silver ore. Gold and many other elements are also often present.

Compare with Antimony (p. 7), Allemontite (p. 6), Stibnite (p. 20), Bismuthinite (p. 21), and Jamesonite (p. 54).

The principal ore of Lead and often very valuable because of its Gold and Silver content.

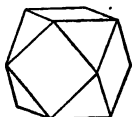


FIG. 9.

See Fig. 11.

**46. ALTAITE.**  $\text{PbTe}$ .

Hardness 3.

Lustre. — Metallic.

Color. — Tin-white or yellowish. **Tarnishes bronze-yellow.**

Streak. — Grayish black.

Cleavage. — Poor cubic. Slightly sectile.

S. G. — 8.16.

B. B. — On charcoal, fuses easily with characteristic flame and sublimates and is entirely volatile except for a trace of Ag which may be present.

Occurs usually massive in rather small pieces disseminated through the gangue; rarely in cubical crystals.

The tarnish on a mineral of this character is distinctive.



**GALENITE GROUP.**

*Members.* — Argentite, Hesseite, Petzite, Galenite, Altaite.

*Composition.* — Monosulphides or tellurides of the heavy metals.

*Crystallization.* — Holohedral isometric.

*Additional.* — All are between 2 and 3 in hardness, have dark colors and streaks, are heavy, have metallic lustres, and fuse easily.



FIG. 10 — Molybdenite, Quebec, Canada.



FIG. 11. — Galenite, Joplin, Missouri.

**54. CHALCOCITE.**  $\text{Cu}_2\text{S}$ .

Hardness 2.5-3.

*(Copper Glance.)*

Lustre. — Metallic, or dull when tarnished.

Color. — **Dark lead-gray. Frequently tarnished dull black or green.**

Streak. — Lead-gray.

**When pure, cuts easily, leaving a polished surface.****No cleavage. Smooth conchoidal fracture when compact.**

S. G. — 5.5-5.8.

B. B. — On charcoal, fuses easily and boils with spurting.

Occurs usually compact massive, sometimes finely granular; also in orthorhombic crystals which are sometimes twinned in star-like forms, and often appear hexagonal. Usually associated with other ores of Cu.

Compare with Tetrahedrite (p. 58), Tennantite (p. 58), Argentite (p. 24), Hessite (p. 25), Petzite (p. 26), and Tenorite (p. 82).

A valuable ore of Copper.

**SPHALERITE GROUP.**

**58. SPHALERITE.**  $ZnS$ . Hardness 3.5-4.

(*Blende; Zinc-, Rosin-, or Ruby-Blende; Jack; Rosin- or Black-Jack; Rosin- or Ruby-Zinc; False Galena; etc.*)

Lustre. — **Resinous** to sub-metallic.

Color. — **Yellow, brown, black, red, green, white.**

Streak. — White, yellow, brown. **Always lighter in color than the mineral itself.**

Cleavage. — **Perfect dodecahedral.**

Brittle.

Opaque to transparent.

May show triboluminescence.

S. G. — 3.9-4.1.

B. B. — On charcoal, yields sublimate of zinc oxide.  
Fuses with difficulty.

Occurs compact, fine-grained to cleavable massive, sometimes fibrous, stalactitic or botryoidal, and in perfect to indistinct inclined hemihedral isometric crystals which are often twinned.

Associated with Galenite and silver minerals.

Hardness combined with streak should be sufficient to distinguish from all similar minerals.

It is an important ore of Zinc and an impure variety yields most of the Cadmium of commerce.



FIG. 12.  
Rounded Crystal.

See Fig. 14.



FIG. 13.

**63. ALABANDITE.**  $MnS$ .

Hardness 3.5-4.

*(Manganese Blende.)*

Lustre. — Submetallic.

Color. — Iron-black. May have a brown tarnish.

Streak. — **Dark green.**

Cleavage. — Good cubic.

Brittle.

S. G. — 4.

B. B. — Gives a Mn bead after thorough roasting on charcoal. Fuses.

• Soluble in dilute HCl, giving off  $H_2S$ .

Occurs usually granular massive, and rarely in inclined hemihedral isometric crystals.

Found as a vein mineral with other metallic sulphides.

**The streak should be sufficient to distinguish it from all similar minerals.**

Not economically important but may, by alteration, form other Manganese minerals.

**SPHALERITE GROUP.**

*Members.* — Sphalerite, Alabandite.

*Composition.* — Monosulphides of metals.

*Crystallization.* — Inclined hemihedral isometric.

*Additional.* — The hardness of both is 3.5 to 4, and both have cleavage.



**FIG. 14.** — Botryoidal Sphalerite, Aspen, Colorado.

**CINNABAR-MILLERITE GROUP.****66. CINNABAR.** HgS.

Hardness 2-2.5.

*(Vermilion, Mercury Blende.)*

Lustre. — Adamantine to earthy.

Color. — **Cochineal-red, scarlet**, reddish brown, black (due to organic impurities).Streak. — **Scarlet** to brownish red.

Cleavage. — Good to poor hexagonal prismatic, seldom recognizable.

Brittle.

Transparent to opaque.

S. G. — **8-8.2.**

B. B. — Wholly volatile, yielding poisonous fumes. Gives Hg and S reactions.

If the powder is moistened with HCl and rubbed on a bright copper coin, the latter will be coated with Mercury.

Occurs in granular or earthy masses, as a brilliant scarlet powder, as a crystalline or earthy incrustation, and, rarely, as tabular or prismatic trapezohedral tetartohedral hexagonal crystals, usually small and transparent.

**Usually found in light-colored, altered rocks, and is rarely associated with other than gangue minerals.**

Compare with Cuprite (p. 80), Hematite (p. 85), Rutile (p. 97), Realgar (p. 18), Proustite (p. 57) and Crocoite (p. 263).

The only important ore of Mercury.

67. **COVELLITE.**  $\text{CuS}$ . Hardness 2.5.  
(*Indigo Copper, Blue Copper.*)

Lustre. — Submetallic, resinous or dull.

Color. — **Indigo-blue** or darker.

Streak. — Black (shining).

Cleavage. — **Perfect basal.** Thin leaves are flexible.

Opaque.

**Turns purple when moistened with water.**

S. G. — 4.51.

B. B. — Emits odor of S and burns with a blue flame,  
on charcoal, fusing to a globule.

Occurs massive, with or without a crystalline surface,  
and either cleavable or granular, in platy aggregates, and,  
rarely, as tabular rhombohedral hemihedral hexagonal  
crystals, apparently holohedral.

The change of color when moistened is distinctive on a  
mineral of this character.

An ore of Copper.

**70. MILLERITE.**  $\text{NiS}$ .  
(*Capillary Pyrites.*)

**Hardness 3-3.5.**

Lustre. — Metallic.

Color. — **Brass-yellow** to bronze-yellow. Sometimes shows a gray, iridescent tarnish.

Streak. — Greenish black.

Brittle, but the hair-like crystals are elastic.

S. G. — 5.3-5.65.

B. B. — Fuses on charcoal to a brittle, magnetic globule.

Occurs in semi-botryoidal crusts with a radiating structure and in hair- or needle-like hexagonal crystals in either delicate, radiating groups or complexly interwoven.

Compare with Marcasite (p. 47).

It is a valuable ore of Nickel. It is probable that the Nickel in Pyrrhotite is present as Millerite.



**71. NICCOLITE.**  $\text{NiAs}$ . Hardness 5-5.5.  
(*Copper Nickel, Arsenical Nickel.*)

Lustre. — Metallic.

Color. — **Light copper-red with a dark tarnish.**

Streak. — Light brownish black.

**Very fine grained, smooth structure.**

Brittle.

S. G. — 7.33-7.67.

B. B. — On charcoal, fuses easily, leaving a magnetic residue.

Occurs usually massive; rarely reniform with a columnar structure, arborescent, or in small, poorly formed hexagonal crystals.

Compare with Copper (p. 11), Pyrrhotite (p. 38) and Bornite (p. 40).

An important ore of Nickel.

- 74. PYRRHOTITE.**  $\text{Fe}_n\text{S}_{n+1}$ . Hardness 3.5–4.5.  
(*Magnetic Pyrites, Munding.*)

Lustre. — Metallic.

Color. — **Brownish or bronze-yellow.** Tarnishes.

Streak. — Grayish-black.

Uneven fracture. Brittle.

**Magnetic.**

S. G. — 4.61.

B. B. — On charcoal, fuses to a black, magnetic mass.

Occurs granular massive, in scattered grains, and, rarely, in small tabular hexagonal crystals.

*Varieties.*

*Nickeliferous.*

Pyrrhotite frequently contains as much as 5% nickel.

### **TROILITE.**

A constituent of many meteorites.

**Differs from all other minerals which it may resemble in being magnetic.** The powder can always be picked up by a magnet and the mineral will sometimes attract the magnet, like Magnetite.

The nickeliferous variety is one of the principal ores of Nickel.

(Note: The "n" in the formula is usually 11, but it is sometimes 5, 7, 8, or 16.)

**CINNABAR-MILLERITE GROUP.**

*Members.* — Cinnabar, Covellite, Millerite, Niccolite, Pyrrhotite.

*Composition.* — Monosulphides and arsenides of metals.

*Crystallization.* — Rhombohedral hemihedral, trapezohedral tetartohedral, and holohedral hexagonal.

The group is not well characterized.

## INTERMEDIATE SULPHIDES.

**78. BORNITE.**  $\text{Cu}_5\text{FeS}_4$ . Hardness 3-3.5.

(*Peacock Ore, Horse-Flesh Ore, Purple or Variegated Copper Ore.*)

Lustre. — Metallic.

Color. — **Dark reddish brown** — “**pinchbeck**”-brown — on a fresh fracture, **speedily tarnishing blue, purple or iridescent.**

Streak. — Grayish black.

Uneven to conchoidal fracture. Brittle.

S. G. — 4.9-5.4.

B. B. — Fuses on charcoal to a brittle, black, magnetic globule.

Occurs compact to granular massive and, rarely, in small isometric crystals.

Is often associated with, or intimately mixed with, Chalcocite (p. 30).

Compare with Copper (p. 11), Niccolite (p. 37), and Pyrrhotite (p. 38).

A valuable ore of Copper.

**83. CHALCOPYRITE.**  $\text{CuFeS}_2$ . **Hardness 3.5-4.**

(*Copper Pyrites, Pyritous Copper, Peacock Ore, Fools' Gold, Yellow Copper Ore.*)

Lustre. — Metallic.

Color. — **Bright brass-yellow.** Iridescent tarnish.

Streak. — **Greenish black.**

**Brittle.** Uneven fracture.

S. G. — 4.1-4.3.

B. B. — Fuses with scintillation on charcoal to a brittle, magnetic globule.

Occurs usually massive or scattered through the gangue in small particles; also in sphenoidal hemihedral tetragonal crystals which closely resemble isometric forms.

Compare with Gold (p. 9) and Pyrite (p. 43); also Bornite (p. 40) when tarnished.

This is one of the most important ores of Copper and frequently carries considerable amounts of Gold and Silver.

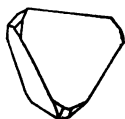


Fig. 15.

84. **STANNITE.**  $\text{Cu}_2\text{S.FeS.SnS}_2$ .      -      Hardness 4.  
(*Tin Pyrites, Bell Metal Ore.*)

Lustre. — Metallic.

Color. — **Greenish gray.** The presence of Chalcopyrite often gives a yellowish tinge. May tarnish bluish.

Streak. — **Black.**

Brittle: Uneven fracture.

S. G. — 4.3–4.52.

B. B. — On charcoal, fuses in the reducing flame and in the oxidizing flame yields a coating of white tin oxide.

Occurs massive or granular, never crystallized, and is frequently associated with Chalcopyrite (p. 41).

Compare with Tetrahedrite (p. 58).

Too rare to be considered an ore of Tin.

DISULPHIDES, ETC.

PYRITE GROUP.

85. **PYRITE.**  $\text{FeS}_2$ . **Hardness 6-6.5.**  
*(Pyrites, Iron Pyrites, White Iron, Wild Iron, Fools' Gold.)*

Lustre. — Metallic.

Color. — **Pale to full brass-yellow.** Tarnishes iridescent to brown.

Streak. — Black.

Cleavage. — **Usually none** apparent. Otherwise, poor to good cubic.

Brittle. Fracture conchoidal to uneven.

S. G. — 4.95-5.10.

B. B. — On charcoal, burns with a blue flame, yielding  $\text{SO}_2$  fumes and leaving a magnetic residue.

Occurs in well formed and frequently very complex **parallel hemihedral isometric crystals**; also massive and in any shape, as botryoidal, stalactitic, reniform or globular. Sometimes finely granular.

Compare with Gold (p. 9), Pyrrhotite (p. 38), Chalcopyrite (p. 41), and Marcasite (p. 47).

Enormous quantities of Pyrite are used in the manufacture of sulphuric acid, and large amounts contain sufficient Copper, Gold or Silver to constitute an ore of these metals.



FIG. 16.

See Figs. 17 and 18.

**87. SMALTITE.**  $(\text{CoNi})\text{As}_2$ . Hardness 5.5–6.  
(*Smaltine, Gray Cobalt, Tin-white Cobalt.*)

**88. OHLOANTHITE.**  $(\text{NiCo})\text{As}_2$ . Hardness 5.5–6.

Lustre. — Metallic.

Color. — Tin-white to steel-gray with a tendency towards a pinkish tint. Tarnishes gray or iridescent.

Streak. — Grayish black.

Cleavage. — None to poor octahedral.

Brittle.

S. G. — 6.4–6.6.

B. B. — Fuses on charcoal to a globule, yielding an arsenical odor.

Occurs usually granular massive or in parallel hemihedral isometric crystals like Pyrite (p. 43); rarely in imitative shapes.

Often alters to, and is associated with, **ERYTHRITE**, an earthy, pink arsenate of cobalt.

Compare with Cobaltite (p. 45), Lollingite (p. 48), and Arsenopyrite (p. 49).

These form the chief ores of Cobalt, which is principally used in the manufacture of pigments.



**89. COBALTITE.**  $\text{CoAsS}$ .

Hardness 5.5.

(*Cobalt Glance, Cobaltine.*)

Lustre. — Metallic.

Color. — Tin-white to steel-gray, **usually with a pinkish or violet tint.**

Streak. — Grayish black.

Cleavage. — None to fair cubical.

Brittle.

S. G. — 6.63.

B. B. — On charcoal, fuses to a magnetic globule, giving As and S fumes.

Occurs commonly granular to compact massive or in parallel hemihedral isometric crystals like Pyrite (p. 43).

Occasionally alters to, and is associated with, Erythrite, an earthy, pink arsenate of cobalt.

Compare with Smaltite (p. 44), Lollingite (p. 48), and Arsenopyrite (p. 49).

A valuable ore of Cobalt.

**PYRITE GROUP.**

*Members.* — Pyrite, Smaltite, Chloanthite, Cobaltite.

*Composition.* — Disulphides and diarsenides of metals.

*Crystallization.* — Parallel hemihedral isometric.

*Additional.* — All are light in color, have a metallic lustre, a dark streak, and are about 6 in hardness.



FIG. 17.—Pyrite in Rhodochrosite, Alicante, Colorado.



FIG. 18.—Pyrite, Elba.

**MARCASITE GROUP.**

**96. MARCASITE.**  $\text{FeS}_2$ . Hardness 6-6.5.

(*White Pyrites, White Iron, Cozcomb and Spear Pyrites.*)

Lustre. — Metallic.

Color. — Pale brass-yellow. **Paler than Pyrite.**

Streak. — Grayish or brownish black.

Cleavage. — **Usually none** apparent; sometimes poor prismatic at angle of  $105^\circ$ .

Brittle. Uneven fracture.

S. G. — 4.87.

B. B. — On charcoal, burns with a blue flame, yielding  $\text{SO}_2$  fumes and leaving a magnetic residue.

Occurs in **orthorhombic crystals**, usually tabular or twinned complexly and united in crest- or spear-like forms; also stalactitic, with a radiating structure and drusy surface, globular, reniform, or imitative.

**More apt to show imitative shapes than Pyrite.**

Compare with Gold (p. 9), Pyrrhotite (p. 38), Chalcopyrite (p. 41), and Pyrite (p. 43).

The uses are the same as for Pyrite (p. 43), q. v.

It is more apt to decompose than Pyrite and is thus even less desirable than that mineral in building stone.



**FIG. 19.**

**97. LOLLINGITE.**  $\text{FeAs}_2$ .

Hardness 5–5.5.

*(Leucopyrite,  $\text{Fe}_3\text{As}_4$ .)*

Lustre. — Metallic.

Color. — **Silver-white** to steel-gray.

Streak. — Grayish black.

Cleavage. — None, or fair basal.

Brittle. Uneven fracture.

S. G. — 7–7.4.

B. B. — On charcoal, fuses to a magnetic globule with reactions for As. Yields metallic As sublimate in the closed tube.

Occurs usually as grains disseminated through a **gangue which is frequently Hornblende** (p. 154); also massive and, rarely, in orthorhombic crystals closely resembling those of Arsenopyrite (p. 49).

*Variety.***GLAUCOPYRITE.**

A cobalt-iron arsenide.

Compare with Arsenopyrite (p. 49).

Has no value unless it carries Gold, as is sometimes the case.

**98. ARSENOPYRITE.**  $\text{FeAsS}$ . Hardness 5.5–6.  
(*Mispickel, Arsenical Pyrites.*)

Lustre. — Metallic.

Color. — Silver-white to grayish white. May have yellow tarnish.

Streak. — Grayish black.

Cleavage. — **Good prismatic at angle of about  $112^\circ$ .**

Brittle.

S. G. — 5.9–6.3.

B. B. — On charcoal, fuses to a magnetic globule with reactions for As. In the closed tube, yields a sublimate of  $\text{As}_2\text{S}_3$ , orange when **hot**, and yellow, cold.

**When struck with a hammer, emits sparks and the odor of As.**

Occurs cleavable columnar, granular or compact massive, as disseminated grains, and as simple orthorhombic crystals.

*Variety.*

### DANAITE.

Contains some Cobalt.

Compare with Smaltite (p. 44), Cobaltite (p. 45), and Lollingite (p. 48).

Most of the Arsenic of commerce is obtained from this mineral, which also may carry enough Gold or Cobalt to make it an ore of those metals.



FIG. 20.

**MARCASITE GROUP.**

*Members.* — Marcasite, Lollingite, Arsenopyrite.

*Composition.* — Disulphides and diarsenides of metals.

*Crystallization.* — Orthorhombic.

*Additional.* — All are light in color, have a metallic lustre, a dark streak, and are hard minerals — between 5 and 6 1/2.

**SYLVANITE GROUP.**

**104. SYLVANITE.**  $(\text{Au,Ag})\text{Te}_2$ . **Hardness 1.5-2.**

Lustre. — Metallic, brilliant.

Color. — Silver-white, inclining to yellow, to steel-gray in the Graphic Tellurium.

Streak. — **Like the color.**

Cleavage. — **Good pinacoidal.**

Brittle.

S. G. — 7.9-8.3.

B. B. — On charcoal, fuses easily with a green flame to a gray globule, giving a dense, white sublimate, which burns off with a green flame. After long blowing, gives a yellow, malleable button.  
Gives Te reaction described under Hessite (p. 25).

Occurs in vertically striated, bladed or prismatic, indistinct monoclinic crystals, and granular.

*Variety.*

**GRAPHIC TELLURIUM.**

Flat crystals, grouped together so as to resemble Hebrew characters.

Characterized by hardness, color and cleavage.

A very valuable ore of Gold and Silver.

**105a. CALAVERITE.**  $\text{AuTe}_2$ .**Hardness 2.5.**

Lustre. — Brilliant metallic.

Color. — **Pale brass-yellow** to almost white.Streak. — **Yellowish gray.**Cleavage. — **None.**

Uneven to sub-conchoidal fracture. Brittle.

S. G. — 9.04.

B. B. — Like Sylvanite (p. 51), q. v.

Occurs massive, non-crystalline.

Compare with the members of the Tellurium, Pyrite, and Marcasite groups (pp. 4-8, 43-50), and with Silver (p. 10) and Sylvanite (p. 51).

Calaverite always contains a little Silver, as well as Gold, and is a very valuable ore of both those metals.



**SYLVANITE GROUP.**

*Members.* — Sylvanite, Calaverite.

*Composition.* — Tellurides of Gold or of Gold and Silver.

*Crystallization.* — Sylvanite is monoclinic but Calaverite does not crystallize.

*Additional.* — Both are light colored, have a brilliant metallic lustre, are about 2 in hardness, and act very similarly B. B.

## SULPHO-SALTS.

## SULPHARSENITES AND SULPHANTIMONITES.

**130. JAMESONITE.**  $\text{Pb}_4\text{FeSb}_6\text{S}_{14}$ . Hardness 2-3.  
(*Feather Ore.*)

Lustre. — Metallic.

Color. — Steel-gray to lead-gray.

Streak. — Grayish black.

Cleavage. — **Perfect pinacoidal.** (Not as evident as upon Stibnite.)

Brittle.

S. G. — 5.5-6.

B. B. — Fuses very easily and volatilizes rapidly, yielding the characteristic Pb and Sb sublimates.

Occurs in bladed, parallel or divergent aggregates, frequently **striated parallel to the direction of elongation**; also fibrous to compact massive, as needle-like crystals, and in hair- or cobweb-like forms.

Is usually associated with Quartz and is frequently coated with lead antimonate as a yellow powder.

Compare with Stibnite (p. 20) and Galenite (p. 27).

Some varieties contain enough Silver to make them valuable.

**136. BOURNONITE.**  $3 \left\{ \begin{smallmatrix} \text{Pb} \\ \text{Cu}_2 \end{smallmatrix} \right\} \text{S.Sb}_2\text{S}_2$  **Hardness 2.5-3.**

**Lustre.** — Metallic, brilliant.

**Color.** — Steel-gray to iron-black.

**Streak.** — Like color.

**Cleavage.** — None or, rarely, poor pinacoidal.

**Rather brittle.** Fracture, sub-conchoidal to uneven.

**S. G.** — 5.7-5.9.

**B. B.** — On charcoal, fuses easily and gives Sb and Pb sublimates.

Occurs fine-grained massive and in **thick, tabular, orthorhombic crystals** with the prism faces often striated.

Compare with Galenite (p. 27), Chalcocite (p. 30) and Tetrahedrite (p. 58).

Too rare to be valuable.

- 144. PYRARGYRITE.**  $\text{Ag}_3\text{SbS}_3$ . Hardness 2.5.  
(*Ruby Silver, Red Silver, Dark Ruby or Red Silver, Antimonial Ruby or Red Silver.*)

Lustre. — Adamantine to metallic.

Color. — **Black, but red by transmitted light**; sometimes reddish gray.

Streak. — **Purplish red.**

Brittle. Uneven to conchoidal fracture.

S. G. — 5.81.

B. B. — Fuses easily with spurting, on charcoal, yielding a dense Sb sublimate and finally giving a globule of malleable Ag.

Occurs compact massive, disseminated in the form of flakes or films, and in hemimorphic, rhombohedral hemihedral hexagonal crystals. Usually associated with other silver minerals.

Compare with Realgar (p. 18), Cinnabar (p. 34), Proustite (p. 57), Hematite (p. 85), and Cuprite (p. 80).

An important ore of Silver.

- 145. PROUSTITE.**  $\text{Ag}_3\text{AsS}_3$ . Hardness 2-2.5.  
(*Ruby or Red Silver, Light Ruby or Red Silver, Arsenical Ruby or Red Silver.*)

Lustre. — Brilliant adamantine.

Color. — **Scarlet-vermilion.**

Streak. — **Scarlet.**

Brittle. Uneven to conchoidal fracture.

S. G. — 5.6.

**B. B.** — On charcoal, fuses easily, giving odors of As and S, yields As sublimate, and finally gives a globule of malleable Ag.

Occurs compact massive, disseminated as grains through the gangue, encrusting, and in hemimorphic, rhombohedral hemihedral hexagonal crystals. Usually associated with other silver minerals.

Compare with Realgar (p. 18), Cinnabar (p. 34), Pyrargyrite (p. 56), Hematite (p. 85), and Cuprite (p. 80).

**A valuable ore of Silver.**

**148. TETRAHEDRITE.**  $\text{Cu}_3\text{Sb}_2\text{S}_7$ . Hardness 3-4.5.

**149. TENNANTITE.**  $\text{Cu}_3\text{As}_2\text{S}_7$ . Hardness 3-4.5.

*(Gray Copper includes both of these minerals.)*

Lustre. — Metallic.

Color. — **Steel-gray** to iron-black. Tennantite is apt to be light and may be brownish or reddish.

Streak. — **Gray, brown or reddish**, the last two being more characteristic of Tennantite than of Tetrahedrite.

**No cleavage. Uneven fracture.** Brittle.

S. G. — 4.4-5.1.

B. B. — On charcoal, fuses, the reactions differing with the composition.

Occurs coarse- or fine-grained or compact massive and in **modified isometric tetrahedrons**, or other inclined hemihedral forms.

#### *Varieties.*

The varieties are based upon the composition, some of the elements which frequently replace Copper to a considerable extent being: Zinc, Iron, Mercury, Silver, Lead, Tin, and Cobalt.

Compare with Chalcocite (p. 30) and Bournonite (p. 55).

Frequently contain enough Silver to make valuable ores of that metal, as well as of Copper.



FIG. 21.

153. **STEPHANITE.**  $\text{Ag}_3\text{SbS}_4$ .  
(*Brittle Silver.*)

**Hardness 2-2.5.**

Lustre. — Metallic.

Color. — Iron-black.

Streak. — Iron-black.

**Very brittle.** Uneven to sub-conchoidal fracture.

S. G. — 6.2-6.3.

B. B. — On charcoal, fuses very easily with spurting to a globule, yielding the sublimate of antimony oxide. After long blowing, yields metallic Silver.

Occurs compact to granular massive, as small particles disseminated through the gangue, and in tabular or short prismatic, six-sided orthorhombic crystals.

Compare with Argentite (p. 24), Chalcocite (p. 30), and Tetrahedrite (p. 58).

**A rare ore of Silver.**

**156. POLYBASITE.**  $(\text{Ag,Cu})_3\text{SbS}_4$ . **Hardness 2-3.**

Lustre. — Metallic.

Color. — Iron-black; **cherry-red in thin splinters.**

Streak. — Black.

Brittle. Uneven fracture.

Almost opaque.

S. G. — 6-6.2.

B. B. — On charcoal, fuses easily with spurting to a globule, giving the antimony (sometimes arsenic) oxide sublimate.

Occurs usually in **six-sided, tabular orthorhombic crystals with beveled edges**, the basal-pinacoid being often marked with triangular striations.

**The appearance is distinctive.**

A very rare ore of Silver.



## SULPHARSENATE.

158. **ENARGITE.**  $\text{Cu}_3\text{AsS}_4$ .

Hardness 3.

Lustre. — Bright metallic.

Color. — **Iron-black** to dark gray.Streak. — **Black.**Cleavage. — **Perfect prismatic** at angle of about  $98^\circ$ .

Brittle.

S. G. — 4.44.

B. B. — On charcoal, fuses and gives faint sublimes of As, Sb, and, often, Zn.

Occurs usually **columnar, cleavable massive**; also granular and in **lustrous orthorhombic crystals with striated prisms.**

The only mineral combining the above color, streak, and cleavage.

An important ore of Copper.



FIG. 22.

## HALOGEN SALTS.

## HALITE GROUP.

166. **HALITE.** NaCl.

Hardness 2.5.

*(Salt, Common Salt, Rock Salt.)*

Lustre. — Vitreous.

Color. — Colorless, white, yellow, brown, reddish, etc., due to impurities.

Streak. — White.

Cleavage. — **Perfect cubic.**

Transparent to translucent.

Taste. — **Saline.**

S. G. — 2.1–2.6.

B. B. — Decrepitates violently. Fuses easily in the closed tube. Soluble in water.

Occurs granular to compact massive, cleavable massive, earthy, more rarely columnar or fibrous, and in isometric crystals, frequently showing cavernous faces. The fibrous variety is usually an efflorescence.

The taste is distinctive.

The uses of Halite (Salt) are well known. It is also the source of most of the Sodium and sodium compounds.

See Fig. 23.

169. **CERARGYRITE.**  $\text{AgCl}$ . **Hardness 1-1.5.**  
(*Horn Silver.*)

Lustre. — **Waxy to resinous**; rarely dull.

Color. — Pearl-gray, greenish, whitish to colorless.  
Becomes violet-brown on exposure to light.

Streak. — White, shining.

**Very sectile. Cuts like wax.**

Translucent.

S. G. — 5.55.

B. B. — Fuses very easily with an unpleasant odor, yielding a button of Ag. If rubbed on moistened Zinc or Iron, it swells, turns black, and is reduced to spongy, metallic Silver.

Occurs usually as a crust, looking like wax or horn; sometimes columnar or in isometric crystals; rarely in earthy masses.

*Varieties.*

**CERARGYRITE, EMBOLITE** —  $\text{Ag}(\text{Cl}, \text{Br})$ , **BROMYRITE** —  $\text{AgBr}$ , **IODOBROMITE** —  $\text{Ag}(\text{Cl}, \text{Br}, \text{I})$ , and **IODYRITE** —  $\text{AgI}$  — are so nearly alike in appearance and value that they may all be conveniently grouped under the first name.

The appearance is so distinctive as to make confusion with other minerals very improbable.

Very important ore of Silver.

**HALITE GROUP.**

*Members.* — Halite, Cerargyrite, Embolite, Bromyrite, Iodobromite.

*Composition.* — Haloids.

*Crystallization.* — Holohedral isometric.

*Additional.* — All are of non-metallic lustre and rather soft, some very much so, but the group is not particularly well characterized.



FIG. 23. — Halite, Borax Lake, California.

**175. FLUORITE.  $\text{CaF}_2$ . Hardness 4.**

(*Fluor Spar; False Emerald, Amethyst, etc.*)

Lustre. — Vitreous.

Color. — Almost all colors, with green, violet, purple, colorless or white the commoner.

Streak. — White.

Cleavage. — **Perfect octahedral.**

Brittle.

Transparent to translucent.

Phosphoresces when gently heated.

S. G. — 3-3.25.

B. B. — In forceps or on charcoal, fuses to an enamel, giving a red flame.

Occurs usually in groups of glassy, transparent cubical isometric crystals, rarely grouped in parallel position, forming an octahedron; also cleavable massive, coarse to fine granular, and, rarely, earthy.

The crystals often show different tints by reflected and transmitted light and the massive varieties are often banded in zigzag lines.

The appearance, hardness, and cleavage should be distinctive.

Compare with Halite (p. 62), Cryolite (p. 66), Quartz (p. 69), Calcite (p. 109), and Sodalite (p. 163).

Is used by smelters as a flux and in several arts and trades.

See Figs. 24 and 40.

**183. CRYOLITE.**  $\text{Na}_3\text{AlF}_6$ .**Hardness 2.5.**Lustre. — **Greasy** to vitreous.

Color. — Colorless to snow-white, sometimes reddish or brownish.

Streak. — White.

Cleavage. — **Poor basal and prismatic at angles of nearly 90°.**

Brittle.

Translucent to transparent.

S. G. — 2.97.

B. B. — On charcoal, fuses very easily with a yellow flame to a clear globule, opaque when cold.

Occurs cleavable massive and occasionally in monoclinic crystals resembling isometric cubes and octahedrons.

Often associated with Galenite (p. 27) or Siderite (p. 115).

The appearance, hardness, and cleavage should be distinctive.

Compare with Halite (p. 62), Fluorite (p. 65), Quartz (p. 69), and Calcite (p. 109).

Was once the sole source of metallic Aluminum but is no longer used in the extraction of that metal except as a flux or bath.

It is in demand for the manufacture of several chemicals.

**193. ATACAMITE.**  $\text{Cu}_2\text{ClH}_3\text{O}_2$ .

Hardness 3-3.5.

Lustre. — Adamantine to vitreous.

Color. — Bright green to various shades of the same.

Streak. — **Apple-green.**

Cleavage. — **Perfect pinacoidal.**

**Usually transparent or translucent.**

S. G. — 3.76.

**B. B. — Gives an azure-blue flame without the aid of HCl.**

Occurs in radiating or confused aggregates of slender, striated orthorhombic crystals; also, fibrous or granular to compact massive and as sand.

Compare with Malachite (p. 127) and Olivenite (p. 242).

A rare ore of Copper.



**FIG. 24.** — Fluorite, Cumberland, England.



## OXIDES.

## OXIDES OF SILICON.

210. **QUARTZ.**  $\text{SiO}_2$ .**Hardness 7.***Phenocrystalline Varieties.*

**Lustre.** — Splendent to nearly dull **vitreous**; sometimes greasy.

**Color.** — Colorless or white when pure; all colors due to impurities.

**Streak.** — White or light tints.

**No cleavage. Conchoidal fracture when crystallized and uneven fracture when massive.**

**Transparent.**

**S. G.** — 2.65.

**B. B.** — Unaltered.

Occurs in distinct trapezohedral tetartohedral **hexagonal crystals with pyramidal terminations and horizontally striated prisms**; also radiating with drusy, crystalline surface, massive, coarse to fine granular, and as sand. In all cases there is a definite internal molecular arrangement, which either manifests itself in a definite external form or is made "evident" by means of polarized light and the compound microscope or through other proper tests.

*Varieties.*

The varieties are nearly all based on color, the various tints being due to impurities, often present in such minute quantities as to make it impossible to determine their character with certainty.

**ROCK CRYSTAL.**

Colorless, or almost colorless.

**AMETHYST.**

Purple to violet. Usually in crystals. Color probably due to Manganese.

**ROSE.**

Rose-red to pink. Always massive. Color possibly due to Titanium or Manganese.

*Yellow Quartz*, **FALSE TOPAZ** or **CITRINE**.

Light yellow. Massive or in crystals. Color probably due to Iron.

**SMOKY QUARTZ**, "**SMOKY TOPAZ**," or **CAIRNGORM**.

Dark brown to black. Usually complexly crystallized. Color due to some organic substance.

**MILKY** or **GREASY**.

White and nearly opaque. Usually massive.

**FERRUGINOUS.**

Containing, or coated with, yellow oxide of iron.

**AVENTURINE.**

Spangled with glistening scales of various minerals.

*Quartz with Inclusions.*

Two of the commonest of these are Rutile (p. 97) and Tourmaline (p. 192).

**CAT'S EYE or TIGER EYE.**

Chatoyant, bright yellow to dark brown with included, parallel fibres of Crocidolite (p. 156).

Compare Phenocrystalline Quartz with Opal (p. 76), Beryl (p. 159), Iolite (p. 160), Nephelite (p. 161), and Topaz (p. 179).

Rock Crystal is used in the cheaper jewelry and is cut for optical purposes. Water-clear, polished spheres of this material are highly valued.

The colored varieties are also used in cheap jewelry and the Amethyst has been a prized gem from very ancient times.

Enormous quantities are used as a flux in smelting operations and also in the manufacture of abrasives, glass, etc.

See Figs. 28 and 46.

*Cryptocrystalline Varieties.*

Lustre. — **Dull to earthy**, sometimes waxy.

Color. — All colors, depending upon impurities.

Streak. — White or light tints.

**No cleavage. Conchoidal fracture.**

**Translucent to opaque.**

S. G. — 2.6–2.7.

B. B. — Unaltered but, in general, it is acted upon more readily by attrition and chemicals — such as hydrofluoric acid — than the Phenocrystalline material.

Occurs **fine grained massive** and mammillary, botryoidal, stalactitic, nodular, or filling or lining cavities in rocks.

It never occurs in crystals since it is made up of a confused jumble of extremely minute particles of Phenocrystalline Quartz, its structure being, therefore, "hidden." These minute particles — and, therefore, the whole mass — are, however — like Phenocrystalline material — crystallized silica.

*Varieties.*

The varieties are based upon both structure and color. Many kinds contain a considerable proportion of Opal silica (p. 76), which gives a higher lustre and makes the grain finer.

*(A) Chalcedonic Quartz.*

It is convenient, but not strictly accurate, to group all the varieties which show a uniform coloration under this term.

**CHALCEDONY.**

Pale blue, gray or drab.

**CARNELIAN.**

Translucent, pale to deep red.

**CHRYSOPTASE.**

Apple-green, the color being due to  $\text{NiO}$ .

**PRASE.**

Dull, leek green.

**JASPER.**

Opaque, dull red, brown, yellow, etc.

**HELIOTROPE OR BLOODSTONE.**

Prase, showing small spots of blood-red Jasper.

**FLINT.**

Smoky-gray or brown to nearly black nodules, occurring in chalk. Translucent and containing considerable Opal silica (p. 76), which is apt to be dissolved out on the surface, leaving a white, porous coating of crystalline silica.

**CHERT.**

Impure, coarse-grained, opaque, gray or brown Flint.

**HORNSTONE.**

Like Chert but is apt to be finer grained and more splintery, and was deposited in horizontal layers.

**BASANITE, LYDIAN STONE OR TOUCH-  
STONE.**

Velvety black.

**(B) AGATE.**

Material showing Chalcedonic Quartzes of **two or more different colors**. The colors are white, gray, light to dark brown, red, black (rare), and light blue or other tints (very rare). Material showing very brilliant or strongly contrasting colors has been artificially tinted.

*Banded Agate.*

The materials of different colors are arranged in **curved, parallel bands**.

*Irregularly clouded Agate.***RUIN or FORTIFICATION AGATE.**

When polished, shows peculiar markings, described by the name.

**MOSS AGATE.**

Translucent material with brown or green, moss-like or dendritic splotches scattered throughout the mass.

**(C) ONYX.**

Bands of different colored materials arranged in **flat, parallel planes**.

**SARDONYX.**

Bands of Carnelian with either white, brown or black material.

**(D) Pseudomorphous Quartz.**

Under this head are found the **PETRIFIED and AGATIZED WOODS**.

(E) *Rock Quartz.*

### **QUARTZ SANDSTONE.**

Fine grains cemented together with  $\text{SiO}_2$ ,  $\text{Fe}_2\text{O}_3$ , or  $\text{CaCO}_3$ .

### **ITACOLUMNITE.**

Flexible sandstone. A considerable proportion of mica scales joining the Quartz grains allows the material to be easily bent without breaking.

### **QUARTZITE.**

A sandstone with the interstices between the grains completely filled with Phenocrystalline Quartz, forming a compact, granular rock.

Compare Cryptocrystalline Quartz with Opal (p. 76), Datolite (p. 184), and Thomsonite (p. 203).

The colored varieties are cut and polished in enormous quantities, being used in jewelry and as ornamental stones.

Sandstone is one of the most important of building materials and Quartzite is used in the same way but to a less extent.

Quartz is the commonest solid substance on the surface of the earth.

See Fig. 29.

**212. OPAL.**  $\text{SiO}_2 + n \text{H}_2\text{O}$ .

**Hardness 5.25-6.5.**

Lustre. — **Greasy vitreous.**

Color. — All colors.

Streak. — White.

**Very smooth, conchoidal fracture.**

Transparent to translucent.

S. G. — 1.9-2.3.

B. B. — Infusible, but becomes opaque. Some yellow varieties turn red.

More readily soluble in hydrofluoric acid and alkalis than Quartz.

Occurs massive in veins and filling cavities in rocks; also botryoidal, stalactitic, and earthy. **Is amorphous silica.**

#### *Varieties.*

The varieties are based on color and structure.

#### **PRECIOUS OPAL.**

Milky, blue, yellow, brown, red, or black opal, **showing internal reflections of various colors**, commonly red or green.

#### **FIRE OPAL.**

Red, brown or yellow material, showing fire-like reflections but no play of color as in Precious Opal.

#### **COMMON OPAL.**

Included under this head are all the typical opals without play of color or other special, distinguishing features.



**OPAL-AGATE.**

Agate-like in structure.

**JASP-OPAL.**

Of the color of red or yellow Jasper.

**WOOD-OPAL.**

Wood, petrified with Opal. The colors are sometimes exquisite. May or may not show the woody structure.

**HYALITE.**

Colorless, transparent drops or botryoidal coatings.

**GEYSERITE OR SILICEOUS SINTER.**

Opaque, rather porous, usually dull lustered material deposited from hot, siliceous water.

**FIORITE OR PEARL SINTER.**

Translucent, porous to firm incrustations, showing a pearly lustre, deposited from hot, siliceous water and formed also by the decomposition of siliceous volcanic rocks about fumeroles.

**DIATOMACEOUS EARTH, INFUSORIAL EARTH,  
FULLERS' EARTH, TRIPOLITE, Etc.**

A very fine-grained, white earth, resembling Chalk (p. 111) but harsher to the touch and capable of scratching glass when rubbed upon it. It is composed of the siliceous remains of very minute plants or animals and is either loose or moderately compacted.

Compare with Quartz (p. 69), Datolite (p. 184), and Thomsonite (p. 203).

Compare the earthy varieties with Chalk (p. 111) and Magnesite (p. 114).

The Precious and Fire Opals are very beautiful gems. Up to recent years they were believed to bring ill-luck to the wearer but they are now very popular.

Other varieties, particularly Wood Opal, are cut and polished for ornamental stones.

The earthy varieties form the base of most metal-polishing powders and have many other uses in the arts and trades.

## ANHYDROUS OXIDES OF THE SEMI-METALS.

**221. OERVANTITE.**  $\text{Sb}_2\text{O}_4$ .  
(*Antimony Ochre.*)

Hardness 4-5.

Lustre. — Greasy or pearly to **dull**.

Color. — Shades of **yellow** to nearly white or reddish white.

Streak. — Yellowish white to white.

Brittle. — Conchoidal to uneven fracture.

Opaque.

**S. G. — 4.08.**

**B. B. —** In forceps, infusible and unaltered. On charcoal, readily reduced to metallic antimony.

Occurs usually massive with a prismatic structure, as a crust or powder, and in indistinct, acicular orthorhombic crystals.

Usually associated with Stibnite (p. 20) and other Antimony ores, being formed by their alteration.

**The association is usually distinctive.**

## ANHYDROUS OXIDES OF THE METALS.

### PROTOXIDES.

**224. OUPRITE.**  $\text{Cu}_2\text{O}$ . **Hardness 3.5-4.**  
(*Red Oxide of Copper, Ruby Copper.*)

Lustre. — Adamantine or sub-metallic to dull.

Color. — Various shades of red; sometimes nearly black.  
Often **carmine**.

Streak. — Brownish red, **shining**.

Brittle.

Transparent to opaque.

S. G. — 5.85-6.15.

B. B. — On charcoal, blackens, fuses, and is reduced to metallic Copper. In the forceps, fuses and colors the flame emerald-green.

Occurs coarse to fine-grained massive, earthy, and in **simple or complicated, well-formed or elongated isometric crystals**, which are really trapezohedral hemihedral but the forms rarely make this apparent.

*Variety.*

### CHALCOTRICHITE.

Elongated parallel to the octahedron axis into capillary forms.

Compare with Cinnabar (p. 34), Proustite (p. 57), and Hematite (p. 85).

An important ore of Copper.

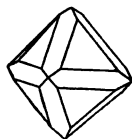


FIG. 25.

**228. ZINCITE.**  $\text{ZnO}$ . **Hardness 4-4.5.**

*(Red Zinc Ore, Red Oxide of Zinc.)*

Lustre. — Sub-adamantine to sub-metallic.

Color. — **Dark red to orange-red.**

Streak. — **Orange-yellow.**

Cleavage. — **Perfect basal**, not always apparent.

Translucent to sub-translucent.

Brittle.

S. G. — 5.43-5.7.

B. B. — Infusible. In closed tube, blackens, but regains the original color when cool.

Occurs in **lamellar masses**, granular, and, rarely, in hemimorphic hexagonal crystals.

**Usually associated with Calcite** (p. 109), **Franklinite** (p. 92), and **Willemite** (p. 171).

Compare with Realgar (p. 18).

An ore of Zinc.

**230. TENORITE.**  $\text{CuO}$ . Hardness 3-4.

(*Melaconite, Black Oxide of Copper, Black Copper.*)

Lustre. — Usually **dull** when massive and metallic when in scales.

Color. — **Black** to iron-gray.

Streak. — **Black**.

Scales slightly flexible. Conchoidal to uneven fracture.

Opaque.

May soil the fingers when earthy.

S. G. — 5.82-6.25.

B. B. — Infusible.

Occurs in dull earthy to compact shining masses, and as thin, metallic scales. It is a common **alteration product of other Cu minerals**, which it coats, or **with which it is associated**.

*Varieties.*

**MELACONITE.**

This term is often used as a synonym for Tenorite, but should be applied only to the black, earthy material.

Compare with Chalcocite (p. 30), Tetrahedrite (p. 58), Tennantite (p. 58), Argentite (p. 24), Hessite (p. 25), Petzite (p. 26), and Hematite (p. 85).

## SESQUIOXIDES.

### HEMATITE GROUP.

**231. CORUNDUM.**  $\text{Al}_2\text{O}_3$ .

**Hardness 9.**

Lustre. — Vitreous to adamantine.

Color. — All colors. Usually gray when massive.

Streak. — White.

**Perfect rhombohedral — nearly rectangular — parting due to twinning. Parting faces usually finely cross-hatched with striations at nearly right angles.**

Brittle. Very tough when compact.

Translucent to transparent.

S. G. — 3.95-4.1.

B. B. — Unaltered.

Occurs pseudo-cleavable massive, coarse to fine granular, and in rhombohedral hemihedral hexagonal crystals, the basal-pinacoid being frequently triangularly striated. The larger crystals are apt to be rough and rounded.

It is also found in the form of water-rounded pebbles.

#### *Varieties.*

##### (A) *Gem Varieties.*

These are transparent and often of fine color. The trade name for all colors is Sapphire. The varieties are based upon differences of color.

### ORIENTAL EMERALD.

Light to deep green.

### ORIENTAL RUBY.

Red with a slight purple tint.

**ORIENTAL SAPPHIRE.**

Light to deep blue. The **STAR SAPPHIRE** shows a star-like, opalescent figure when viewed in the direction of the vertical axis of the crystal.

**ORIENTAL TOPAZ.**

Yellow.

**ORIENTAL AMETHYST.**

Purple.

**(B) ADAMANTINE SPAR.**

Coarse crystals, masses showing a well developed parting, and granular. Slightly translucent.

**(C) EMERY.**

Opaque, finely granular material, of dark color, and mixed with Magnetite (p. 91) or Hematite (p. 85).

The hardness is sufficient to distinguish from all similar minerals.

The gem varieties are very beautiful and extremely valuable, some varieties costing more than Diamonds of equal weight.

Adamantine Spar and Emery are the most important natural abrasive substances and great quantities of both are used for grinding and polishing.



FIG. 26.



**232. HEMATITE.**  $\text{Fe}_2\text{O}_3$ . Hardness 5.5–6.5.  
(*Red Oxide of Iron, Red Iron Ore.*)

Lustre. — Metallic to earthy.

Color. — Steel-gray to black, reddish black, and red.

Streak. — **Bright red to reddish brown.**

No cleavage but often possesses a foliated or lamellar structure due to parting parallel to the basal pinacoid.

Uneven fracture. Brittle.

S. G. — 4.9–5.3.

B. B. — Infusible. On charcoal, becomes magnetic.

Occurs in compact platy, columnar, radiated, kidney-shaped or micaceous masses; also granular, loose and earthy, oölitic, and in rhombohedral hemihedral hexagonal crystals.

The crystals are thin tabular and grouped in more or less parallel position, larger and thicker and often showing rounded faces, or scaly to micaceous.

*Varieties.*

**SPECULAR IRON.**

Very brilliant plates or crystals.

**RED-OCHRE** or **RUDDLE.**

Earthy, more or less impure material.

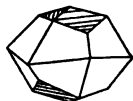


FIG. 27.

**MARTITE.**

Pseudomorphous after Magnetite (p. 91).

Compare with Cinnabar (p. 34), Cuprite (p. 80), Ilmenite (p. 86), Magnetite (p. 91), and Limonite (p. 104).

The greatest proportion of all the iron-ore mined is Hematite. It is also used in considerable amounts for manufacturing cheap paint, as chalk used in marking assay crucibles, as a polishing powder, etc.

See Fig. 31.

**233. ILMENITE.**  $\text{FeTiO}_3$ .

Hardness 5-6.

*(Menaccanite, Titanic Iron Ore.)*

Lustre. — Sub-metallic.

Color. — Iron-black.

Streak. — **Reddish brown** to brownish black.**Small surfaces show a flat conchoidal fracture.** Brittle.

Opaque.

Attracts magnetic needle feebly.

S. G. — 4.5-5.

B. B. — Gives following test for Ti.

Grind *very fine* and boil with HCl in a test-tube until dissolved to a yellow liquid, which, if Sn or Zn be boiled in it, will turn to violet.

Occurs compact massive, granular, in thin plates, as imbedded grains, and as sand. Rarely in thick tabular or acute rhombohedral tetartohedral hexagonal crystals.

*Varieties.***ISERINE.**

Pseudomorphous after magnetite.

Compare with Hematite (p. 85), Spinel (p. 88), Magnetite (p. 91), Franklinite (p. 92), Chromite (p. 93), and Limonite (p. 104).

Is used in the lining of puddling furnaces.

It is very difficult to smelt and this fact makes other iron ores with which it may be associated less valuable than they otherwise would be.

**HEMATITE GROUP.**

*Members.* — Corundum, Hematite, Ilmenite.

*Composition.* — Sesquioxides ( $M_2O_3$ ).

*Crystallization.* — Rhombohedral hemihedral and rhombohedral tetartohedral hexagonal.

The group is not well characterized.



FIG. 28. — Quartz, Hot Springs, Arkansas.

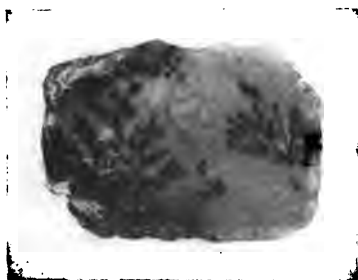


FIG. 29. — Moss Agate.

## INTERMEDIATE OXIDES.

## SPINEL GROUP.

**234. SPINEL.**  $MgO \cdot Al_2O_3$ .**Hardness 8.**Lustre. — **Vitreous** to almost dull.

Color. — Commonly black but also red, blue, green, yellow, and brown.

Streak. — **White**.

Brittle. Conchoidal fracture.

Transparent to opaque.

S. G. — 3.5–4.1.

B. B. — Infusible, but may change color.

Occurs usually in simple or twinned octahedral crystals. Also as water-worn pebbles. Often associated with gem Corundum.

The surface of some varieties is apt to be hydrated and so soft as to be easily scratched with a knife.

*Varieties.***RUBY SPINEL** or **BALAS RUBY**.

A Magnesia Spinel, red in color and transparent to translucent.

**CEYLONITE.**

An Iron Magnesia Spinel, dark green, brown or black in color and opaque.

**CHLOROSPINEL.**

A Magnesia Iron Copper Spinel, grass-green in color.

**PICOTTITE or CHROME SPINEL.**

A Magnesia Chromium Iron Spinel, dark yellowish brown to greenish brown in color and translucent to nearly opaque.

*Note*; All varieties contain Aluminum.

Compare with Corundum (p. 83) and the other members of this group.

The transparent varieties are semiprecious and are used as gems.

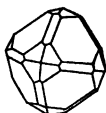


FIG. 30.

- 236. Gahnite.**  $\text{ZnO} \cdot \text{Al}_2\text{O}_3$ . Hardness 7.5–8.  
(*Zinc Spinel.*)

Lustre: — Vitreous to greasy.

Color. — **Dark green to greenish black**, also bluish black, yellowish or grayish brown.

Streak. — **Gray** or grayish green.

Brittle. Conchoidal to uneven fracture.

Sub-transparent to opaque.

S. G. — 4–4.6.

B. B. — Infusible and yields Zn tests with flux.

Occurs in grains or octahedral crystals.

Compare with Spinel (p. 88).

**237. MAGNETITE.**  $\text{FeO} \cdot \text{Fe}_2\text{O}_3$ . Hardness 5.5–6.5.  
(*Magnetic or Octahedral Iron Ore.*)

Lustre. — Metallic to sub-metallic or dull.

Color. — Iron-black.

Streak. — Black.

Octahedral parting due to twinning often well developed.

**Strongly attracted by the magnet and is sometimes itself magnetic.**

Brittle. Sub-conchoidal to uneven fracture.

S. G. — 5.17.

B. B. — Practically infusible.

Occurs compact and laminated massive, coarse to fine granular, as sand, and in octahedral crystals, the faces of which often show octahedral twinning striations or striations produced by oscillation of the octahedron and dodecahedron faces.

*Variety.*

### **LODESTONE.**

A natural magnet, possessing the property of polarity.

**This is the only mineral excepting native Iron (p. 16) which is strongly attracted by the magnet.**

A very pure and valuable ore of Iron.

**239. FRANKLINITE.**  $\left\{ \begin{smallmatrix} \text{Fe} \\ \text{Zn} \\ \text{Mn} \end{smallmatrix} \right\} \text{O} \cdot \left\{ \begin{smallmatrix} \text{Fe} \\ \text{Mn} \end{smallmatrix} \right\}_2 \text{O}_3$ . Hardness 5.5–6.5.

Lustre. — Metallic to dull.

Color. — Iron-black.

Streak. — **Reddish brown to brownish black.**

**Octahedral parting due to twinning usually well developed.**

Sometimes slightly magnetic.

Brittle. Conchoidal to uneven fracture.

S. G. — 5.07–5.22.

**B. B. — Infusible.**

Occurs compact to platy massive, coarse to fine granular, and in octahedral crystals which pass into rounded grains.

**Usually associated with Zincite (p. 81), Calcite (p. 109), and Willemite (p. 171).**

Compare with Hematite (p. 85), Ilmenite (p. 86), the other members of this group, and Limonite (p. 104).

It is an ore of Zinc and one of the by-products of its recovery is used in the making of manganese steel. A poor grade of dark paint has been made of the ground material.

See Fig. 32.



**241. CHROMITE.**  $\text{FeO} \cdot \text{Cr}_2\text{O}_3$ .  
(*Chrome-iron Ore.*)

Hardness 5.5.

Lustre. — **Vitreous, splendid**, to metallic or sub-metallic.

Color. — Black.

Streak. — **Dark brown.**

Brittle. Uneven fracture but **each grain shows a very smooth conchoidal fracture with a high lustre.**

Opaque.

S. G. — 4.32–4.57.

B. B. — Infusible, but may fuse slightly in the reducing flame and then becomes magnetic.

Occurs usually coarse to fine granular or as disseminated grains; also compact massive and, rarely, in small octahedral crystals.

**Usually associated with Serpentine (p. 219) and often showing a finely botryoidal, green coating of ZARATITE, a hydrated, basic nickel carbonate.**

Compare with Hematite (p. 85), Ilmenite (p. 86), and the other members of this group, particularly Magnetite (p. 91).

Chromite is the source of nearly all the Chromium chemical compounds and chrome paints, and is also used in making a hard steel.

**SPINEL GROUP.**

*Members.* — Spinel, Gahnite, Magnetite, Franklinite, Chromite.

*Composition.* — Intermediate oxides ( $\text{RO} \cdot \text{R}_2\text{O}_3$ ).

*Crystallization.* — Holohedral isometric.

*Additional.* — All are too hard to be scratched with a knife.



FIG. 31. — Martite, Twin Peaks, Utah.



FIG. 32. — Franklinite in Calcite, Franklin Furnace, New Jersey.

**242. CHRYSOBERYL.**  $\text{BeO} \cdot \text{Al}_2\text{O}_3$ .**Hardness 8.5.**

Lustre. — Vitreous.

Color. — Light yellow-green to emerald-green. **The dark varieties are sometimes purplish red by transmitted light.**

Streak. — White.

Brittle. Uneven to conchoidal fracture.

Transparent to translucent.

S. G. — 3.5–3.84.

B. B. — Unaltered.

Occurs in thin to thick, tabular orthorhombic crystals with the macro-pinacoid vertically striated. Contact or polysynthetic twins are common, these being usually tabular and showing pointed or featherlike striations on the largest faces.

Sometimes found as water-worn pebbles, resembling green glass. This and other varieties may exhibit a bluish chatoyancy, or may be asteriated.

*Varieties.***ALEXANDRITE.**

Emerald-green, but purplish red by transmitted or artificial light. Probably colored by Cr.

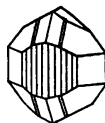


FIG. 33.

**CAT'S EYE or CYMOPHANE.**

Chatoyant, yellowish green material.

Compare with Emerald (p. 159), Beryl (p. 159), Chrysolite (p. 170), Epidote (p. 186), and Tourmaline (p. 192).

The transparent varieties are valued and used as gems.

## DIOXIDES.

## RUTILE GROUP.

**248. CASSITERITE.**  $\text{SnO}_2$ .

Hardness 6-7.

Lustre. — Adamantine to dull.

Color. — Brown, black or red; sometimes gray or yellow.

Streak. — White or **very light brown**.

Brittle. Uneven to sub-conchoidal fracture.

Opaque to translucent.

**S. G.** — 6.8-7.1.

B. B. — Infusible. On charcoal, powder becomes luminous and yellow.

Occurs in well formed tetragonal crystals, often short and forming "knee-shaped" contact twins; as disseminated grains, and, most frequently, as botryoidal or reniform masses or water-worn pebbles with a concentric or radiating fibrous structure; also compact to granular massive.



FIG. 34.  
"Knee-Shaped"  
Twin.

*Varieties.***TIN-STONE.**

In crystals and massive.

**WOOD TIN.**

Botryoidal and reniform varieties, with radiating fibrous, concentric structure and resembling dry wood in colors.

**STREAM TIN.**

Water-worn pebbles or grains.

Compare with Rutile (p. 97) and Wolframite (p. 271).

The source of all Tin.

**250. RUTILE.**  $\text{TiO}_2$ .

Hardness 6–6.5.

Lustre. — Adamantine to sub-metallic.

Color. — Reddish brown, red, yellowish, black, etc.  
**Deep red by transmitted light.**

Streak. — Light brown.

Cleavage. — Poor prismatic sometimes developed.

Brittle. Uneven to sub-conchoidal fracture.

Transparent to opaque.

**S. G. — 4.2.**

B. B. — Infusible. Yields Ti test described under Ilmenite (p. 86).

Occurs in tetragonal crystals which often show **vertical striations or deep furrows on the prism faces**. Contact twins of several habits are common. These include "knee-shaped" twins, "spear-head" twins, "sixlings" and "eightlings." Often found slender acicular with deep striations and indistinct crystallization; also as hair-like inclusions in other minerals. Occasionally occurs compact massive.

*Variety.***NIGRINE.**Black material containing 2% to 3%  $\text{Fe}_2\text{O}_3$ .

Compare with Cassiterite (p. 96).

It is used to give the required bluish tint to artificial teeth. Its presence seriously impairs the value of iron ores, with which it is frequently associated; but when pure it is in demand for the manufacture of certain grades of steel.

See Fig. 35.

**RUTILE GROUP.**

*Members.* — Cassiterite, Rutile.

*Composition.* — Dioxides.

*Crystallization.* — Tetragonal.

*Additional.* — Both are too hard to be scratched with a knife, are frequently of a brown color and adamantine lustre and often occur in "knee-shaped" twins.



FIG. 35. — Rutile "Eightling," Arkansas.

**253. BROOKITE.  $\text{TiO}_2$ .**

Hardness 5.5-6.

Lustre. — Adamantine to sub-metallic.

Color. — Brown, yellowish, reddish, and black.

Streak. — White to yellowish or grayish.

Brittle. Uneven to sub-conchoidal fracture.

Translucent to opaque.

S. G. — 3.87-4.01.

B. B. — Infusible. Yields Ti test described under Ilmenite (p. 86.).

Occurs either in thin, tabular, translucent, brown orthorhombic crystals, which are often highly modified, or in black, opaque pyramidal crystals which are often dull in lustre.

The appearance is distinctive.

Too rare to have any use.

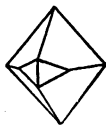


FIG. 36.

- 254. PYROLUSITE.**  $\text{MnO}_2$ . **Hardness 1-2.5.**  
(*Gray or Black Oxide of Manganese, Manganese Peroxide.*)

Lustre. — Metallic to dull.

Color. — Black to dark steel-gray.

Streak. — **Black, often sooty.**

Rather brittle.

**Usually soils the fingers.**

S. G. — 4.73-4.86.

B. B. — Infusible, but becomes brown.

Occurs in indistinct, probably pseudomorphic, crystals, as radiating needles or fibres, as velvety crusts, and, more rarely, granular to compact massive and stalactitic.

**Often found in alternate layers with Psilomelane (p. 108).**

The hardness and streak are sufficient to distinguish Pyrolusite from all the minerals with which it is apt to be confused.

It is used to decolorize glass when the tints are due to the presence of  $\text{FeO}$ , to color glass purple, in the manufacture of electric dry-batteries, chlorine, and oxygen, and as an oxidizing agent in many ways.



## HYDROUS OXIDES.

## DIASPORE GROUP.

**256. DIASPORE.**  $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$ .      **Hardness 6.5-7.**

**Lustre.** — Vitreous. Pearly on cleavage face.

**Color.** — Pink, violet, green, brown, yellowish, gray, white or colorless. Sometimes dichroic, violet and green.

**Streak.** — White.

**Cleavage.** — **Perfect pinacoidal.**

Very brittle.

Transparent to sub-translucent.

**S. G.** — 3.3-3.5.

**B. B.** — Infusible and usually decrepitates.

Occurs in thin scales, flat, prismatic orthorhombic crystals, and foliated massive.

Compare with Lepidolite (p. 208) and Margarite (p. 212).

**257. GOETHITE.**  $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$ . Hardness 5-5.5.  
(*Brown Hematite, Brown Iron Ore.*)

Lustre. — Sub-metallic, sub-adamantine, silky, dull.

Color. — Yellow, dark brown, brownish black. Rarely reddish but often blood-red by transmitted light.

Streak. — Brownish to ochre-yellow.

Cleavage. — **Perfect pinacoidal.**

Brittle.

Opaque to translucent.

S. G. — 4-4.4

B. B. — Thin splinters fuse black and magnetic.

Occurs fibrous or needle-like, foliated or in scales, as velvety crusts, botryoidal or reniform or stalactitic with a concentric and radiating structure, and in indistinct, vertically striated, prismatic orthorhombic crystals.

Compare with Limonite (p. 104), from which it cannot usually be distinguished and with which it is classed commercially.

An ore of Iron.

**258. MANGANITE.**  $\text{Mn}_2\text{O}_3 \cdot \text{H}_2\text{O}$ .  
(*Gray Oxide of Manganese.*)

**Hardness 4.**

**Lustre.** — Metallic to sub-metallic.

**Color.** — Iron-black to dark steel-gray.

**Streak.** — **Reddish brown to brownish black.**

**Cleavage.** — **Perfect pinacoidal.**

**Brittle.**

**S. G.** — 4.2–4.4.

**B. B.** — Infusible.

Occurs in long, deeply striated, prismatic orthorhombic crystals with basal-pinacoids, in bundles of such crystals, and, rarely, massive, columnar, granular or stalactitic.

Usually associated with other Mn minerals.

The hardness and streak are sufficient to distinguish it from all similar minerals.

**259. LIMONITE.**  $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ . Hardness 5–5.5.  
*(Yellow or Brown Hematite, Yellow or Brown Iron Ore.)*

Lustre. — Sub-metallic, varnish-like, silky, dull.

Color. — Brown, yellow, nearly black.

Streak. — **Yellowish brown to yellow.**

Opaque.

S. G. — 3.6–4.

B. B. — Thin splinters fuse black and magnetic.

Occurs usually in **botryoidal, stalactitic or mammillary forms with a fine, fibrous radiated structure and a varnish-like surface**; also concretionary, massive, and earthy.

#### *Varieties.*

#### **BOG IRON ORE.**

Formed in marshy places. Usually loose or porous in texture and enclosing vegetation.

#### **YELLOW OCHRE or UMBER.**

Earthy material, carrying clay, sand, etc.

Compare with Hematite (p. 85) and Goethite (p. 102).

It is the commonest ore of Iron but is of lowest grade and most impure. It is also used in the manufacture of some cheap yellow and brown paints.

**261. BAUXITE.**  $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$ . Hardness 1-3.

Lustre. — Dull to earthy.

Color. — White, yellow, red, brown.

Streak. — Like color.

Conchoidal fracture.

Opaque.

Usually contains, and has the odor of, Kaolin.

S. G. — 2.55.

B.B. — Infusible. **Completely soluble in salt of phosphorus bead.**

Occurs usually massive; also oolitic and clayey. **Often shows round, concretionary spots or rings in a lighter colored clay-like material.** Often colored red by  $\text{Fe}_2\text{O}_3$ .

Compare with Kaolinite (p. 225).

Now the chief source of Aluminum. It is also used for basic furnace or converter linings and in the manufacture of alum.

**DIASPORE GROUP.**

*Members.* — Diaspore, Goethite, Manganite, Limonite, Bauxite.

*Composition.* — Hydrous sesquioxides.

*Crystallization.* — Orthorhombic and amorphous.

The group is not well characterized.

**262. BRUCITE.**  $\text{MgO} \cdot \text{H}_2\text{O}$ .**Hardness 2.5.****Lustre.** — Pearly or waxy to vitreous.**Color.** — White or tinted.**Streak.** — White.**Cleavage.** — Good pinacoidal. Cleavage plates flexible.**Sectile.****Usually translucent.****S. G.** — 2.39.**B. B.** — Infusible, but glows brilliantly.

Occurs in foliated masses, fibrous, and, rarely, in tabular rhombohedral hemihedral hexagonal crystals.

Compare with Muscovite (p. 207), Talc (p. 222), and Gypsum (p. 264).

**269. PSILOMELANE.**  $\text{MnO}_2 \cdot \text{H}_2\text{O} + \left\{ \begin{smallmatrix} \text{K}_2\text{O} \\ \text{BaO} \end{smallmatrix} \right\}$ .  
 (*Black Hematite.*) **Hardness 6±.**

Lustre. — Sub-metallic to dull.

Color. — Iron-black to dark gray.

Streak. — **Brownish or grayish black, shining.**

**Smooth, conchoidal fracture.**

Opaque.

S. G. — 3.7–4.7.

B. B. — Infusible.

Occurs in **smooth, amorphous, botryoidal or stalactitic masses, or in layers with Pyrolusite** (p. 100).

*Varieties.*

#### **WAD or BOG MANGANESE.**

Impure mixture of Mn, Fe, Co, Cu, Pb, etc., oxides. Usually loose and earthy with a brown streak and soft enough to soil the fingers. Sometimes harder and compact.

**The hardness, combined with the appearance, is distinctive of Psilomelane.**

This is the commonest Manganese ore and its uses are the same as described under Pyrolusite (p. 100), but its products are less pure.



## ANHYDROUS CARBONATES.

## CALCITE GROUP.

270. **CALCITE.**  $\text{CaCO}_3$ .  
(*Calc-spar.*)

**Hardness 3.**

Lustre. — Vitreous to earthy.

Color. — Colorless or white, and pale to deep shades of yellow, blue, red, violet, green, and brown to black when impure.

Streak. — White.

Cleavage. — **Very perfect rhombohedral at angles of  $105^\circ 5'$  and  $74^\circ 55'$ , being parallel to the "unit rhombohedron" (+R).**

A good parting parallel to  $-\frac{1}{2}$  R often developed by twinning.

Transparent to opaque.

**Double refraction very strong.**

S. G. — 2.72.

B. B. — Infusible but becomes opaque and gives red flame.

**Easily soluble with effervescence in cold, dilute HCl or in any other condition of that acid.**

Occurs in crystals, cleavable to compact massive, coarse to fine granular, stalactitic, nodular, earthy, and, rarely, fibrous or lamellar.

*Varieties.*

*Crystals.*

The crystallization is rhombohedral hemihedral hexagonal.

Most Calcite crystals are found to fall under one of the following habits.

1. *Flat rhombohedral*. —  $\frac{1}{2}$  R is main form. Called **NAIL-HEAD SPAR**.
2. *Steep rhombohedral*. — 2 R is main form.
3. *Steep scalenohedral*. Acutely pointed and often-complexly rounded with steep scalenohedrons the main forms. Called **DOG-TOOTH SPAR**.
4. *Prismatic*. Long and slender. May show prisms of all three orders. Usually terminated by habits 1 or 3, above.
5. *Tabular*. Very flat rhombohedrons and scalenohedrons with, rarely, a basal-pinacoid.  
On all varieties, striations due to oscillation of faces are common.

Twinning parallel to —  $\frac{1}{2}$  R is common and the basal-pinacoid is also sometimes a twinning plane. The former habit is not uncommon on massive, cleavable material and produces twinning striations on cleavage faces.

In orienting broken material, remember that the vertical axis must come out at the intersection of three cleavage faces *which make equal angles with each other*.

### IOELAND SPAR.

Transparent, flawless, colorless, cleavable material.

*Massive.*

### SATIN SPAR.

Fine fibrous with a silky lustre.

### ARGENTINE.

Laminated, with a pearly lustre.

### MARBLE.

Coarse to fine granular, crystalline.

**LIMESTONE.**

Dull, compact, noncrystalline.

**COQUINA.**

A rock made up of shells, etc., cemented together into a hard mass.

**LITHOGRAPHIC STONE.**

A compact limestone with a very fine grained, even texture.

**MARL.**

Earthy material containing much clay.

**OOBITIC LIMESTONE.**

Composed of small spherical particles, looking like fish roe.

**PISOLITIC LIMESTONE.**

Same as above but the particles are larger, often as large as a small pea.

**CHALK.**

Soft, white, earthy material, made up of the remains of deep sea organisms.

*Deposited from Springs, Streams or in Caverns.*

**STALACTITE, STALAGMITE, MEXICAN ONYX.**

Banded or concentric material, with a radiating structure, formed in caves. Stalactites hang from the roof and Stalagmites form on the floor, under the drip of the former.

**TRAVERTINE.**

Banded material, deposited from streams or springs.

**CALCAREOUS TUFFA.**

Very porous Travertine.

Compare with Aragonite (p. 120).

Distinguished from all other similar minerals by acid test, cleavage or hardness.

The uses of Calcite are very many.

Iceland Spar is rare and valuable, being used by opticians. Marble and Limestone are important building materials and the former is carved for various purposes. The latter is used in enormous quantities in the manufacture of lime, as a flux in smelting, in the manufacture of  $\text{CO}_2$  and other chemicals, and in many arts and trades.

Coquina is a fine paving material.

Lithographic Stone is scarce and valuable since it must stand many tests.

The banded material often forms a beautiful and valuable ornamental stone.

See Fig. 39.

**271. DOLOMITE.** (Ca, Mg) CO<sub>3</sub>. Hardness 3.5-4.  
(*Magnesian Spar, Magnesian Limestone.*)

Lustre. — Vitreous to pearly.

Color. — White, pink, yellow, brown, gray.

Streak. — White.

Cleavage. — **Perfect rhombohedral at angles of 106° 15' and 73° 45'.**

Translucent.

S. G. — 2.8-2.9.

**B.B.** — Infusible. **Fragments effervesce vigorously in warm, dilute HCl, but the action is very slow in cold acid.**

Occurs coarse to fine granular or compact massive, and in **warped rhombohedral crystals**, usually grouped with the sharp edges outward, forms other than the unit rhombohedron being rare.

*Varieties.*

### **PEARL SPAR.**

Crystals with a pearly lustre.



**FIG. 38.**  
**Warped**  
**Rhombohedron.**

### **GOLDEN DOLOMITE.**

Crystals with a yellowish brown or golden coating.

**Distinguished from all similar minerals by acid test and appearance.**

The uses are similar to those of Calcite, much Limestone being dolomitic. It is not used, however, in making some of the chemical products made from Calcite (p. 109). Epsom salts are made from Dolomite.

**272. MAGNESITE.**  $\text{MgCO}_3$ .**Hardness 4-4.5.**

Lustre. — **Earthy** when massive. Vitreous when crystallized.

Color. — **White**, yellow or grayish when massive. Brown to **black** when crystallized, due to organic impurities.

Streak. — **White**.

**Conchoidal fracture when earthy massive.**

Cleavage. — **Perfect rhombohedral at angles of  $107^\circ 24'$  and  $72^\circ 36'$  when crystallized.**

Opaque to translucent.

S. G. — 3-3.12.

B. B. — Infusible. **Will effervesce vigorously only in hot, concentrated, or boiling, dilute HCl.**

Occurs in chalk-like lumps, often associated with Serpentine (p. 219); also, rarely, fibrous and in steep rhombohedral crystals, showing a basal plane and resembling distorted octahedrons. Rarely, cleavable massive.

The earthy massive material should be compared with the Opal earths (p. 77), Chalk (p. 111), Hydrozincite (p. 129), and Thaumasite (p. 227). Compare crystals with Spinel (p. 88). Compare cleavable massive variety with Calcite (p. 109) and Dolomite (p. 113).

It is used as a lining for converters, etc.; and in the manufacture of  $\text{CO}_2$ , epsom salts and magnesia.

**273. SIDERITE.**  $\text{FeCO}_3$ .

Hardness 3.5-4.

*(Spathic Iron, Brown Spar.)*

Lustre. — Vitreous to pearly and dull.

Color. — **Brown or gray.** Rarely greenish, reddish, yellowish or black. Tarnishes reddish brown to brownish black.

Streak. — White to yellowish.

Cleavage. — **Perfect rhombohedral at angles of  $107^\circ$  and  $73^\circ$ .**

Translucent to opaque.

S. G. — 3.86.

B. B. — On charcoal, decrepitates, blackens, becomes magnetic, and fuses with great difficulty in thin splinters.

**Will effervesce vigorously only in hot, concentrated HCl.**

Occurs cleavable massive, coarse to fine granular, and in warped rhombohedrons like Dolomite (p. 113); also compact and earthy and, rarely, oolitic, botryoidal or fibrous.

*Varieties.***SPHAEROSIDERITE or CLAY-IRONSTONE.**

Compact material containing much clay, the former being concretionary.

Compare with Sphalerite (p. 31), Dolomite (p. 113), and Smithsonite (p. 117).

A rather uncommon ore of Iron, but it is so pure that the Iron made from it commands a premium.

**274. RHODOCHROSITE.**  $\text{MnCO}_3$ . Hardness **3.5-4.5**.  
(*Manganese Spar.*)

Lustre. — Vitreous to pearly.

Color. — **Dark red or rose-red when transparent; pink or brownish red when translucent or opaque. Surface becomes black upon exposure.**

Streak. — White.

Cleavage. — **Perfect rhombohedral at angles of  $107^\circ$  and  $73^\circ$ .**

Transparent to opaque.

S. G. — 3.45-3.6.

B. B. — Infusible but decrepitates strongly and becomes gray, brown or black. **Will effervesce vigorously only in hot, concentrated, or boiling, dilute HCl.**

Occurs cleavable massive, granular, in warped rhombohedrons like Dolomite (p. 113), and in complexly modified rhombohedral crystals; also, rarely, compact, botryoidal, and incrusting.

**The color will distinguish from all similar minerals except manganiferous Dolomite (p. 113) and Rhodonite (p. 151). To distinguish from these, apply acid and hardness tests, respectively.**

Valueless, but is usually associated with ores of Silver, Manganese, Lead, and Copper.

See Fig. 40.



**275. SMITHEONITE.  $\text{ZnCO}_3$ .****Hardness 5.***(Called Calamine in England.)*

Lustre. — Vitreous to resinous or dull.

Color. — Brown, green, yellow or gray. White when pure.

Streak. — White.

Cleavage. — Perfect rhombohedral at angles of  $107^\circ 40'$  and  $72^\circ 20'$ . Not always very evident.

Translucent to opaque.

May show triboluminescence.

**S. G. — 4.3-4.45.****B. B. — Infusible. Effervesces vigorously in any kind of HCl except cold dilute.**

Occurs stalactitic, botryoidal or as crystalline crusts; also in dull lustered, earthy, cavernous masses. Rarely granular, powdery or in rhombohedral crystals.

The crusts have a **finely fibrous, radiating structure.**

*Variety.***DRY BONE.**

The dull lustered, massive, cavernous material, resembling closely the substance from which it gets its name.

Compare with Sphalerite (p. 31), Siderite (p. 115), and Calamine (p. 191).

A very valuable ore of Zinc, since it requires no roasting before reduction.

**CALCITE GROUP.**

*Members.* — Calcite, Dolomite, Magnesite, Siderite, Rhodochrosite, Smithsonite.

*Composition.* — Carbonates.

*Crystallization.* — Rhombohedral hemihedral hexagonal.

*Additional.* — All have a perfect rhombohedral cleavage at an angle of from  $105^{\circ}$  to  $107^{\circ} 40'$ , varying with the composition.

All are relatively soft, varying from 3 to 5 with the composition.

All effervesce in some condition of HCl, the ease of effervescence varying with the composition.

All may have a vitreous lustre.



FIG. 39. — Calcite, Ouray County, Colorado.



**FIG. 40.** — Rhodochrosite with Octahedral Fluorite,  
Saguache County, Colorado.

## ARAGONITE GROUP.

**277. ARAGONITE.**  $\text{CaCO}_3$ .

Hardness 3.5-4

Lustre. — Vitreous.

Color. — Usually white; sometimes yellow, gray, green or violet.

Streak. — White.

Cleavage. — **None** or poor pinacoidal.

Fracture. — Sub-conchoidal.

Transparent to translucent.

S. G. — 2.94.

B. B. — Infusible, but may whiten and fall to pieces.

**Effervesces vigorously in cold, dilute HCl, or in any other condition of that acid.**

Occurs in distinct orthorhombic crystals which frequently show striations across the terminations, due to twinning; in repeatedly twinned crystals which closely resemble a hexagonal basal pinacoid, prism, etc.; in radiating aggregates of acicular crystals with a six-sided cross-section; also in coral-like shapes, stalactitic, and incrusting; sometimes columnar to fine fibrous.

*Varieties.***FLOS FERRI.**

Delicate, interlacing, and branching stems, closely resembling Tree Corals. Associated with iron-ores.

Calcite sometimes assumes this form.

Compare with Quartz (p. 69), Calcite (p. 109), Strontianite (p. 123), and Natrolite (p. 201).

Rarely occurs in sufficiently large masses to pay to use it in the manufacture of the products for which Calcite (p. 109) is used.

A decisive method of distinguishing between Calcite (p. 109) and Aragonite is the following:

Powder the substance to be tested and boil in dilute cobalt nitrate. If the substance is Calcite, the powder will turn to a green or blue, and, if Aragonite, to a lilac or purple.

See Fig. 44.



FIG. 41.—Twin.

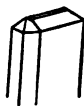


FIG. 42.

**279. WITHERITE.**  $\text{BaCO}_3$ .

Hardness 3-4.

Lustre. — **Greasy vitreous.**

Color. — Yellowish, grayish or white.

Streak. — White.

Cleavage. — **None.**

Uneven to sub-conchoidal fracture.

Translucent.

S. G. — **4.52.**

B. B. — Fuses easily and gives a Ba flame.

**Effervesces vigorously in very dilute, cold HCl but not in cold, concentrated HCl.**

Occurs in masses which frequently show cavities lined with indistinct crystals or with globular forms; also in twinned orthorhombic crystals closely resembling a hexagonal prism and steep pyramid, the prism being deeply, horizontally striated or grooved; sometimes granular; rarely fibrous.

**The lustre, specific gravity, and B. B. tests are distinctive.**

Used in refining beet-sugar and to adulterate white lead.



FIG. 43. — Twin.

**280. STRONTIANITE.**  $\text{SrCO}_3$ .

Hardness 3.5-4.

Lustre. — Vitreous to greasy.

Color. — White or colorless, and pale shades of yellow, green, and brown.

Streak. — White.

Cleavage. — Fair prismatic at angles of  $117^\circ 19'$  and  $62^\circ 41'$ .

Translucent.

S. G. — 3.7.

B. B. — Fuses only on thin edges, but swells and shows Sr flame.

**Effervesces vigorously in very dilute, cold HCl but not in cold, concentrated HCl.**

Occurs in radiating aggregates of imperfect, prismatic crystals; sometimes granular, fibrous or in globular forms, and rarely in orthorhombic crystals, often showing pseudo-hexagonal twinning.

Compare with Aragonite (p. 120).

Large amounts are used in making the "red fire" of pyrotechny and in obtaining sugar from molasses, this being first precipitated as a strontium compound.

**281. CERUSSITE.**  $\text{PbCO}_3$ .

Hardness 3–3.5.

*(White Lead Ore.)*Lustre. — **Adamantine** or greasy to **silky**.

Color. — White, gray or brown.

Streak. — White.

Cleavage. — **None**.Very brittle. **Conchoidal fracture**.

Transparent to nearly opaque.

S. G. — **6.5**.

**B. B.** — Decrepitates and fuses very easily, yielding a lead oxide sublimate and a globule of Pb.

**Effervesces vigorously in hot concentrated or boiling dilute HCl.**

Occurs in **silky, prismatic masses**; granular to compact massive; as disseminated grains, often in Limonite (p. 104); impure and earthy; rarely as orthorhombic crystals; fairly frequently as star-shaped twins; sometimes stalactitic or fibrous.

Compare with Anglesite (p. 259).

Frequently carries Silver and is a valuable ore of that metal, as well as of Lead, since it requires no preliminary roasting before smelting.

See Fig. 45.



**ARAGONITE GROUP.**

*Members.* — Aragonite, Witherite, Strontianite, Cerussite.

*Composition.* — Carbonates.

*Crystallization.* — Orthorhombic.

*Additional.* — All effervesce in some condition of HCl, are usually white, are non-metallic in lustre, and are between 3 and 4 in hardness.



FIG. 44. — Aragonite, Cumberland. England.



**FIG. 45.** — Cerussite, Leadville, Colorado.

## HYDROUS CARBONATES.

**288. MALACHITE.**  $\text{CuCO}_3 \cdot \text{CuO} \cdot \text{H}_2\text{O}$ . Hardness 3.5–4.  
(*Green Carbonate of Copper.*)

Lustre. — **Silky** to dull. Crystals are sub-adamantine.

Color. — **Bright emerald-green.** Often nearly black on exposed surfaces.

Streak. — Green, paler than the color.

Cleavage. — **None.** Uneven fracture.

Translucent to opaque.

S. G. — 3.9–4.03.

B. B. — On charcoal, decrepitates and fuses to a mass of metallic Cu, yielding Cu flame.

**Effervesces vigorously in any condition of HCl.**

Occurs massive or as crusts, with a botryoidal or stalactitic surface, a radiating structure, and a silky lustre; often compact fibrous and banded; also in indistinct, vertically striated, acicular monoclinic crystals; sometimes granular or earthy.

Usually associated with other copper minerals as an alteration product, and with Limonite (p. 104).

Compare with Atacamite (p. 67), Olivenite (p. 242), and Conichalcite (p. 245).

An oxidized ore of Copper, and the compact, banded varieties are cut and polished for use as ornamental stones and in jewelry.

**289. AZURITE.**  $2\text{CuCO}_3 \cdot \text{CuO} \cdot \text{H}_2\text{O}$ . Hardness 3.5-4.  
(*Blue Carbonate of Copper.*)

Lustre. — Vitreous to dull.

Color. — **Dark blue to azure-blue.**

Streak. — Blue.

Brittle. Conchoidal fracture.

Transparent to opaque.

S. G. — 3.8.

B. B. — On charcoal, decrepitates and fuses to a mass of metallic Cu, yielding Cu flame.  
**Effervesces vigorously in any condition of HCl.**

Occurs massive, or in crusts with a velvety appearing and botryoidal surface, or as sharply crystallized but very complex, glassy monoclinic crystals, usually tabular in habit; also earthy.

Usually associated with other copper minerals as an alteration product, and with Limonite (p. 104).

Compare Vivianite (p. 244).

An oxidized ore of Copper, is cut and polished for jewelry, and is manufactured into a poor grade of paint.

**291. HYDROZINCITE.**  $3\text{ZnCO}_3 \cdot 2\text{H}_2\text{O}$ . Hardness 2-2.5.  
(*Zinc Bloom, Earthy Calamine.*)

Lustre. — Dull.

Color. — White, grayish, or yellowish.

Streak. — White.

Conchoidal fracture.

Opaque.

S. G. — 3.58-3.8.

B. B. — Infusible. Effervesces vigorously in any condition of HCl.

Occurs in chalk-like or earthy masses; as incrustations, sometimes with a concentric structure, and, rarely, stalactitic or pisolitic.

Usually associated with Smithsonite (p. 117), or other Zn ores as an alteration product.

Compare with Infusorial earth (p. 77), Chalk (p. 111), and Magnesite (p. 114).

Does not occur in quantities sufficiently large to allow of profitable working as an ore of Zinc.

**296. NATRON.**  $\text{Na}_2\text{CO}_3 + 10\text{H}_2\text{O}$ . **Hardness 1-1.5.**

**Lustre.** — Earthy.

**Color.** — White, yellow or gray.

**Streak.** — White.

**Very brittle.** Conchoidal fracture.

**Tastes alkaline.**

**Opaque.**

**S. G. — 1.44.**

**B. B. —** On charcoal, fuses very easily and is absorbed by the charcoal.

**Effervesces very vigorously in any condition of HCl.**

**Occurs in spongy masses or powdery crusts.**

**Compare with Calcareous Tufa (p. 112).**

**FELDSPAR SERIES.**

*Members.* — Orthoclase, Microcline, Albite, Oligoclase, Labradorite, Anorthite.

*Composition.* — Silicates of aluminum and potassium or aluminum and sodium and calcium, one or both.

*Crystallization.* — Monoclinic or triclinic, the forms being very similar.

*Additional.* — All have a hardness of about 6, a vitreous lustre, two unequally good cleavages at an angle of exactly or nearly  $90^\circ$ , and are apt to be rather light colored.

The following table shows the principle upon which the subdivisions according to composition are based.

Acid Feldspars (Over 60% $\text{SiO}_2$ )	$\left\{ \begin{array}{l} \text{Orthoclase} \\ \text{Microcline} \\ \text{Albite} \\ \text{Oligoclase} \end{array} \right\}$	Alkaline Feldspars [The alkalis (Na and K) prominent].
Basic Feldspars (Under 60% $\text{SiO}_2$ )	$\left\{ \begin{array}{l} \text{Labradorite} \\ \text{Anorthite} \end{array} \right\}$	Lime Feldspars (Large amounts of CaO present.)

## ANHYDROUS SILICATES.

## FELDSPAR SERIES.

## ORTHOCLASE GROUP.

**313. ORTHOCLASE.**  $\text{KAlSi}_3\text{O}_8$ .Hardness **6**.*(Potash Feldspar.)*Lustre. — Vitreous to dull or **stony**.Color. — **Flesh-red** to gray, yellow, white or colorless; rarely green.

Streak. — White.

Cleavage. — **Perfect basal and slightly less perfect clinopinacoidal at angle of  $90^\circ$** . Very rarely a good prismatic cleavage at angle of  $61^\circ 13'$ , usually more distinct parallel to one prism face than to the other.

Brittle.

Transparent to opaque.

S. G. — 2.5–2.62.

B. B. — Very thin splinters are fused with difficulty, giving K flame.

Occurs in cleavable or granular masses and in simple or twinned, monoclinic crystals; rarely crypto-crystalline or lamellar.

Often **associated with Quartz** (p. 69) and **Mica** (pp. 207, 209).*Varieties.**Crystals.*

Both simple and twinned crystals invariably show a basal- and a clinopinacoid with a prism, and a + orthodome is almost always present. Other forms are sometimes shown. Crystals may be divided into the following three habits:



1. *Elongated* parallel to the *clino* axis. This type is the commonest.
2. *Elongated* parallel to the *vertical* axis.
3. *Tabular* parallel to the symmetry plane. This habit is rare.

In orienting crystals, remember that you must hold them so as to make a basal- and a clino-pinacoid and a prism prominent forms, though the prism is not as prominent as the others in the first habit.

The three types of twinning to which Orthoclase crystals are subject — described in the order of frequency of occurrence — are as follows:

1. *Carlsbad*: Usually interpenetration, but sometimes contact, twins, twinning plane being the *ortho-pinacoid* and the plane of union, the *clino-pinacoid*.
2. *Baveno*: Contact twins, the planes of twinning and of union being a *clino-dome*.
3. *Mannebach*: Contact twins, the planes of twinning and of union being the *basal-pinacoid*.

These three types of twinning affect the cleavage as follows:

*Carlsbad*: Breaks up the basal cleavage into right and left portions, one of which will flash light after turning the specimen around its ortho axis to a little over 60° from the flash of the other portion. The clino-pinacoidal cleavage is unaffected.

*Baveno*: Interchanges the two cleavages, bringing two perfect and two slightly less perfect cleavages together on opposite sides of the specimen.

*Mannebach*: Does not affect the cleavages.

### ADULARIA.

**Transparent**, colorless, monoclinic crystals, showing a prism and basal-pinacoid as the main forms, thus **closely resembling rhombohedrons**. Often coated with green Chlorite (p. 215).

**VALENCIANITE.**

**Translucent or opaque material, crystallized like Adularia.**

**SANADINE.**

**Glassy, transparent crystals or grains imbedded in relatively recent, acid volcanic rocks.**

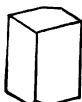
Compare with the other Feldspars, Rhodonite (p. 151), and Wernerite (p. 175).

The light colored varieties are used in the manufacture of glass and porcelain.

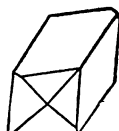
**Ranks next to Quartz in frequency of occurrence.**



**FIG. 46.**  
**Carlsbad Twin.**



**FIG. 47.**  
**Adularia.**



**FIG. 48.**  
**Baveno Twin.**

**315. MICROCLINE.**  $\text{KAlSi}_3\text{O}_8$ .

Hardness 6.

*(Potash Feldspar.)*

Lustre. — **Very brilliant vitreous on cleavage faces to dull or stony.**

Color. — White, yellow, gray, red, and bright green, called **AMAZON STONE.**

Streak. — White.

Cleavage. — **Perfect basal- and slightly less perfect brachy-pinacoidal at angle of about  $89^\circ 45'$ .**

Brittle.

Transparent to opaque.

S. G. — 2.55.

B. B. — Very thin splinters are fused with difficulty, giving K flame.

Occurs in cleavable or granular masses and in simple or twinned crystals exactly like Orthoclase (p. 132) in habit and twinning excepting that they are triclinic.

A combination of the Albite and Pericline types of twinning — see under Albite (p. 137) for a description of these — often produces a **cross-hatched or grating-like appearance on the basal-pinacoid.**

Compare with the other Feldspars, Rhodonite (p. 151), and Wernerite (p. 175).

Much that is called Orthoclase is really Microcline, it being often impossible to distinguish between the two except optically.

Used for the same purposes as Orthoclase (p. 132). Amazon Stone is used in jewelry.

See Fig. 49.

**ORTHOCLASE GROUP.**

*Members.* — Orthoclase, Microcline.

*Composition.* —  $\text{KAlSi}_3\text{O}_8$ .

*Crystallization.* — Monoclinic and triclinic.

*Additional.* — These species are almost identical, the slight differences being noted on the preceding pages.

To distinguish the members of the Orthoclase Group from the minerals in the Plagioclase Group, which follows, remember that the former are very apt to weather to a reddish or reddish brown color, and to occur in rather compact, thickset crystals which often show the effect of Carlsbad twinning (p. 133) on the better cleavage. The frequent association with Quartz (p. 69) is often useful.

The above points are particularly applicable to the Feldspars occurring in rocks.



**FIG. 49.** — Amazon Stone and Smoky Quartz on Albite,  
Florissant, Colorado.

## PLAGIOCLASE GROUP.

**316. ALBITE.**  $\text{NaAlSi}_3\text{O}_8$ . Hardness 6-6.5.  
(*Soda Feldspar, Pericline.*)

Lustre. — Vitreous to pearly.

Color. — **White** or tinted light shades. Sometimes shows a delicate, bluish chatoyancy.

Streak. — White.

Cleavage. — **Perfect basal- and slightly less perfect brachy-pinacoidal at angle of  $86^\circ 24'$ .**

Brittle.

Transparent to opaque.

S. G. — 2.63.

B. B. — Small pieces fuse at under 4, giving Na flame.

Occurs in masses made up of straight or curved laminae, coarse to fine granular, and in small, tabular, triclinic crystals.

**Almost invariably shows fine, albitic twinning striations on the better cleavage — basal — parallel to the poorer cleavage — brachy-pinacoidal. The basal-pinacoid is also thus striated.**

*Twinning.*

Albite occurs twinned after the Carlsbad, Baveno, and Mannebach laws (p. 133) but these are comparatively rare.

The common types are: —

1. *Albite* or *albitic*: Contact twins, usually polysynthetic, the planes of twinning and union being the *brachy-pinacoid*, thus giving rise to the striations mentioned above.

2. *Pericline*: Contact twins, usually polysynthetic, the planes of twinning and union being a possible *macro-dome*, sometimes producing striations on the brachy-pinacoid or poorer cleavage.

*Variety.*

**MOONSTONE.**

**Translucent, with a bluish chatoyancy on basal sections.**  
Some Moonstone is Orthoclase or Oligoclase.

**The color and mode of occurrence are usually perfectly distinctive.**

**See Fig. 49.**

**317. OLIGOCLASE.** Ab,An-Ab,An.\*      Hardness 6-7.  
(*Soda-lime Feldspar.*)

Lustre. — Vitreous to pearly.

Color. — White, reddish, grayish or greenish.

Streak. — White.

Cleavage. — **Perfect basal- and slightly less perfect brachy-pinacoidal at angle of  $86^{\circ} 32'$ .**

Brittle.

Transparent to opaque.

S. G. — 2.66.

B. B. — Fuses easily to a clear or enamel-like glass.

Occurs usually cleavable massive; sometimes compact, and, rarely, in simple or twinned, triclinic crystals like Albite (p. 137).

The crystals and cleavable massive material almost always show albitic twinning striations (p. 137).

*Variety.*

**SUNSTONE.**

Shows internal yellowish or reddish fire-like reflections from Hematite (p. 85) scales.

Compare with the other Feldspars.

\* $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$  = Ab = Albite.

$\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$  = An = Anorthite.

**319. LABRADORITE.**  $\text{AbAn}-\text{AbAn}_*$  Hardness 6-7.  
(*Lime-soda Feldspar.*)

Lustre. — Vitreous to almost pearly.

Color. — **Dark gray**, brown, greenish or colorless. **Usually, a beautiful play of colors parallel to the brachy-pinacoid on cleavable varieties.**

Streak. — White.

Cleavage. — **Perfect basal- and slightly less perfect brachy-pinacoidal at angle of  $86^\circ 4'$ .**

Brittle.

Translucent to opaque.

S. G. — 2.71.

B. B. — Fuses easily to a colorless glass.

Occurs granular or cleavable massive, or in triclinic crystals, usually very thin tabular; rarely cryptocrystalline.

**The crystals and cleavable massive material almost always show albitic twinning striations (p. 137).**

Compare with the other Feldspars.

\*See p. 139.



**320. ANORTHITE.**  $\text{CaAl}_2\text{Si}_2\text{O}_8$ .  
(*Lime Feldspar.*)

Hardness 6-6.5.

Lustre. — Vitreous.

Color. — White, gray or reddish.

Streak. — White.

Cleavage. — Perfect basal- and slightly less perfect brachy-pinacoidal at angle of  $85^\circ 50'$ .

Brittle.

Transparent to opaque.

S. G. — 2.75.

B. B. — Practically infusible.

Occurs in gray or pink cleavable, and white or red granular, masses; also in simple or twinned triclinic crystals.

The crystals and cleavable massive material almost always show albitic twinning striations (p. 137).

*Variety.*

### INDIAN STONE.

White or red granular masses, resembling sandstone.

Compare with the other Feldspars. It is usually very difficult to indentify Anorthite unless it occurs in the Indian Stone habit.

**PLAGIOCLASE GROUP.**

*Members.* — Albite, Oligoclase, Labradorite, Anorthite.

*Composition.* — Silicates of aluminum and calcium and sodium, one or both.

*Crystallization.* — Triclinic.

*Additional.* — These species often occur so similarly that to give their additional points of resemblance would involve giving most of their characteristics.

To distinguish the members of the Plagioclase Group from the minerals in the Orthoclase Group, which precedes the former, remember that the former are very apt to weather to a white or greenish color and to occur in decidedly tabular crystals, most sections of which will be "lath-shaped." The occurrence of striations on the better cleavage, parallel to the poorer, due to albitic twinning (p. 137), is very characteristic, and the rarity of association with Quartz (p. 69) is often a useful point to bear in mind.

The above features are particularly applicable to the Feldspars occurring in rocks.

**321. LEUCITE.**  $\text{KAl}(\text{SiO}_3)_2$ .

Hardness 5.5–6.

Lustre. — Greasy vitreous to dull on the surface.

Color. — **Gray** to white; rarely reddish.

Streak. — White.

No cleavage.

Brittle. Conchoidal fracture.

Transparent to opaque.

S. G. — 2.47.

B. B. — Infusible.

Occurs as grains or *complete* trapezohedral crystals or groups of crystals in volcanic rocks; rarely granular massive.

Compare with Garnet (p. 166) and Analcite (p. 200).

Rock containing Leucite has long been used for mill-stones.

**PYROXENE SERIES.****ORTHORHOMBIC PYROXENE GROUP.****323. ENSTATITE.**  $\text{MgSiO}_3$ .

Hardness 5.5.

Lustre. — Silky or pearly to metalloidal.

Color. — **Yellowish brown**, sometimes grayish or greenish.

Streak. — White.

Cleavage. — **Perfect brachy-pinacoidal parting in addition to a fair prismatic cleavage at an angle of  $88^\circ 16'$ .**

Brittle.

Translucent to opaque.

S. G. — 3.1–3.3.

B. B. — Infusible.

**Occurs lamellar or columnar-fibrous massive.***Variety.***BRONZITE.**

Containing up to 14% Fe and often possessing a bronze-like lustre.

Compare with Hypersthene (p. 145) and Diallage (p. 147).

**324. HYPERSTHENE.** (Mg, Fe) SiO<sub>2</sub>. Hardness 5-6.

Lustre. — Pearly to metalloidal.

Color. — **Dark green or brown to black.**

Streak. — Gray.

Cleavage. — **Perfect brachy-pinacoidal parting in addition to a fair prismatic cleavage at an angle of 88° 20'.**

Brittle.

Translucent to opaque.

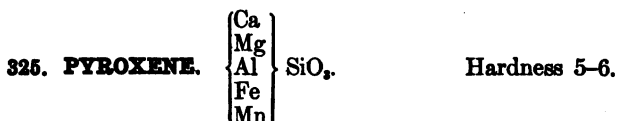
S. G. — 3.4-3.5.

B. B. — Fuses to a black magnetic mass.

**Occurs in foliated or platy masses, which frequently show a peculiar schiller or glistening lustre due to minute tabular scales of doubtful character.**

Compare with Enstatite (p. 144), Diallage (p. 147), and Titanite (p. 229).

## MONOCLINIC PYROXENE GROUP.



Lustre. — Vitreous to dull.

Color. — Usually light to dark green of dull shades, or black; also white or brown.

Streak. — White to greenish.

Cleavage. — Fair prismatic at angle of  $87^\circ 10'$ ; also sometimes a perfect basal parting due to twinning.

Brittle.

Transparent to opaque.

S. G. — 3.2-3.6.

B. B. — Easily to difficultly fusible to a dark — sometimes magnetic — glass.

Occurs usually in prismatic monoclinic crystals with a nearly square or octagonal cross-section, sometimes twinned parallel to the ortho-pinacoid; also in foliated, coarse to fine granular or columnar masses and, rarely, fibrous.

*Varieties.*

*Non-aluminous.*

**DIOPSIDE.** CaMg.

Usually occurs as white or light green, rather glassy crystals.

**HEDENBERGITE.** CaFe.

Grayish green to almost black crystals or lamellar massive; also granular as **COCCOLITE**.

*Aluminous.***DIALLAG.**  $\text{CaMgFeAl}$ .

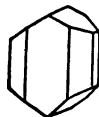
**Light green** or brown material with a foliated structure due to the development of a **perfect ortho-pinacoidal parting**. May be non-aluminous.

**AUGITE.**  $\text{CaMgAlFe}$ .

**Black** and very dark green or brown, short, prismatic crystals, often twinned.

Compare with Amphibole (p. 153), Wernerite (p. 175), Vesuvianite (p. 177), and Epidote (p. 186).

Some of the transparent varieties are sometimes cut as semi-precious gems.



**FIG. 50.**  
**Augite.**

**327. SPODUMENE.**  $\text{LiAl}(\text{SiO}_3)_2$ . Hardness 6.5-7.

Lustre. — Vitreous to stony or dull.

Color. — Grayish white; rarely green or pink; sometimes colorless.

Streak. — White.

Cleavage. — Fair prismatic at angle of  $87^\circ$  and often a perfect ortho-pinacoidal parting, in addition.

Brittle.

Transparent to opaque.

S. G. — 3.16.

B. B. — Swells and fuses with intumescence to a clear or white glass, yielding Li flame when moistened with HCl.

Occurs cleavable massive and in monoclinic crystals, sometimes very large. The smaller crystals are often indistinctly crystallized and the vertical planes are usually striated and grooved.

The common development of the pinacoidal parting produces a platy structure which is quite characteristic.

• *Varieties.*

**HIDDENITE.**

Slender, prismatic, transparent, deep green crystals.

**KUNZITE.**

Slender to stout, prismatic, transparent, pink crystals.

Compare the ordinary material with Orthoclase (p. 132) and Wernerite (p. 175).

Compare Hiddenite with Emerald (p. 159) and Tourmaline (p. 192).

Compare Kunzite with Tourmaline (Rubellite) (p. 192) and Amethyst (p. 70).

The transparent, colored varieties are valuable gems.



**329. WOLLASTONITE.**  $\text{CaSiO}_3$ . Hardness 4.5-5.  
(*Tabular Spar.*)

Lustre. — Vitreous to **silky**.

Color. — **White**, yellowish, reddish or brownish.

Streak. — **White**.

Cleavage. — **Fair basal- and ortho-pinacoidal at angle of  $84^\circ 30'$ .**

Brittle.

Translucent.

S. G. — 2.5-2.9.

B. B. — Fuses fairly easily on the edges, giving Ca flame.

Occurs in compact, cleavable, or **bladed or columnar fibrous masses**, the fibres being usually parallel; rarely in monoclinic crystals.

**Usually associated and mixed with Calcite (p. 109), and often with Garnet (p. 166) and other calcium silicates.**

Compare with Pectolite (p. 150), Tremolite (p. 153), Natrolite (p. 201), and Thomsonite (p. 203).

**330. PECTOLITE.**  $\text{HNaCa}_2(\text{SiO}_3)_2$ .

Hardness 5.

Lustre. — **Silky** to almost vitreous.Color. — **White** or grayish.Streak. — **White**.Cleavage. — Fair basal and ortho-pinacoidal at angle of  $84^\circ 40'$ . Often indistinct.

Brittle.

Translucent to opaque.

S. G. — 2.68–2.78.

B. B. — Fuses very easily to a white enamel. May give out light when broken in the dark.

Occurs as **sharp, radiating fibres or needles**, sometimes of great length; rarely in distinct monoclinic crystals.

The compact, radiating fibrous material is very tough and often quite soft, due to alteration.

Sometimes found massive, fine grained and very tough.

**Often associated with Calcite** (p. 109), **Prehnite** (p. 189), **Zeolites** (p. 196), etc., in cavities in basic, eruptive rocks.

*Variety.***MANGANOPECTOLITE.**

Contains manganese.

Compare with Wollastonite (p. 149), Tremolite (p. 153), Natrolite (p. 201), and Thomsonite (p. 203).

**TRICLINIC PYROXENE GROUP.**

**335. RHODONITE.**  $\text{MnSiO}_3$ . **Hardness 5.5-6.5.**  
(*Manganese Spar.*)

Lustre. — Vitreous to dull.

Color. — **Brownish red to rose-pink.** Often coated with black  $\text{MnO}_2$ , if it has been exposed to the air.

Streak. — White.

Cleavage. — **Fair prismatic at angle of  $87^\circ 32'$ , and poor basal.**

Brittle.

Transparent to opaque.

S. G. — 3.4-3.68.

B. B. — Blackens and fuses easily.

Occurs cleavable to compactly granular massive, as disseminated grains, and as triclinic crystals which are usually rough with rounded edges.

**Often associated with Calcite** (p. 109), **Franklinite** (p. 92), and **Willemite** (p. 171); also with Tetrahedrite (p. 58) and iron ores.

*Varieties.*

**FOWLERITE.**

Zinciferous, pink crystals or foliated masses.

Compare with Rhodochrosite (p. 116) and Orthoclase (p. 132).

Is used in making violet glass or glaze and is sometimes polished for inlaid work.

**PYROXENE SERIES.**

*Members of the Orthorhombic Pyroxene Group* — Enstatite, Hypersthene.

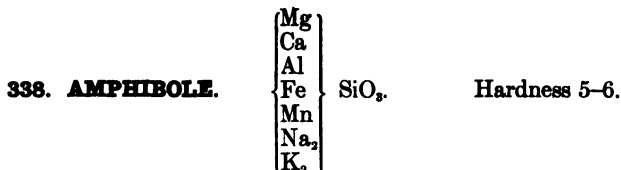
*Members of the Monoclinic Pyroxene Group.* — Pyroxene, Spodumene, Wollastonite, Pectolite.

*Member of the Triclinic Pyroxene Group.* — Rhodonite.

*Composition.* — Silicates of several bases, not including the alkalies.

*Crystallization.* — Orthorhombic, monoclinic and triclinic.

*Additional.* — All Pyroxenes have poor to fair cleavages in two directions at somewhat less than  $90^\circ$ , and a nearly square or octagonal cross-section.

**MONOCLINIC AMPHIBOLE GROUP.**

Lustre. — Vitreous to silky.

Color. — White to black through gray and many shades of green.

Streak. — White or greenish.

Cleavage. — **Perfect prismatic at angle of  $124^\circ 11'$ .**

Brittle to flexible and tough.

Transparent to opaque.

S. G. — 2.9-3.4.

B. B. — Easily to difficultly fusible to a dark — sometimes magnetic — glass.

Occurs usually in **prismatic monoclinic crystals with an acute rhombic or hexagonal cross-section; also fibrous; sometimes columnar or coarse to fine granular; rarely lamellar.** Sometimes crystals are twinned parallel to the ortho-pinacoid, making them appear to be hemimorphic orthorhombic.

*Varieties.**Non-aluminous.***TREMOLITE.**  $\text{CaMg}.$ 

White to gray material, usually bladed and deeply striated or fibrous, often showing a silky lustre.

**ACTINOLITE.**  $\text{CaMgFe}.$ 

Green, bladed, sometimes transparent crystals, usually very long and lying in great confusion as to direction.

**NEPHRITE** or **JADE**.  $\text{CaMgFe}$ .

Extremely tough, fine grained, compact material, varying in color from white to dark green.

**ASBESTUS.**

Any variety of Amphibole except those containing much Al, occurring in long, fine, flexible, easily separable fibres.

**MOUNTAIN LEATHER** and **CORK**.

Thin sheets and thicker pieces of interlaced fibres, often hydrous and white to gray or yellowish in color, and so light that they float on water.

**URALITE.**

Amphibole pseudomorphous after Pyroxene (p. 146).

*Aluminous.***EDENITE**.  $\text{CaMgAl}$ .

White to light green.

**HORNBLLENDE.**

Dark green to **black**, often possessing a horn-like lustre. Crystals often appear to be rhombohedral hemihedral hexagonal.

Compare Tremolite with Wollastonite (p. 149) and Pectolite (p. 150).

Compare Actinolite with Cyanite (p. 182) and Tourmaline (p. 192).

Compare Asbestos with Crocidolite (p. 156) and Chrysotile (p. 219).

Compare Hornblende with Augite (p. 147) and Tourmaline (p. 192).

The many uses of Asbestos are well known.

Jade has been used since prehistoric times for the manufacture of weapons, it being the toughest known stone. In China and India it is still carved into ornaments, etc., and is highly valued.

See Fig. 52.



FIG. 51.  
Hornblende.

**341. CROCIDOLITE.**  $\text{NaFe}(\text{SiO}_3)_2 \cdot \text{FeSiO}_3$ . Hardness 4.

Lustre. — **Silky** to dull.

Color. — **Dark lavender-blue** or dark green.

Streak. — Like color.

**Fibres flexible** and somewhat elastic.

Opaque.

S. G. — 3.2–3.3.

B. B. — Fuses easily with intumescence to a black, magnetic glass, yielding Na flame.

Occurs in compact, fibrous masses, identically like Asbestus (p. 154) in structure.

*Variety.*

**TIGER EYE** or **CAT'S EYE.**

A hard, altered, siliceous variety, deep brown to light yellow in color, and possessing a highly chatoyant lustre.

Tiger Eye is composed of coarse, and Cat's Eye of fine, fibres.

Compare with Asbestus (p. 154) and Chrysotile (p. 219).

The Tiger Eye takes a high polish and is used, either in its natural color or artificially tinted, as an ornamental stone and in cheap jewelry.

See Fig. 53.



**MONOCLINIC AMPHIBOLE GROUP.**

*Members.* — Amphibole, Crocidolite.

*Composition.* — Silicates of several bases, including the alkalies.

*Crystallization.* — Monoclinic.

*Additional.* — All Amphiboles have a perfect prismatic cleavage at an angle of about  $124^\circ$ , and a rhombic or hexagonal cross-section.

Amphiboles are apt to be more decidedly prismatic or fibrous and to occur in simpler crystals than Pyroxenes.



FIG. 52. — Actinolite, Germany.



**FIG. 53.** — Crocidolite (showing silky lustre),  
South Griqualand, Africa.

**344. BERYL.**  $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$ .**Hardness 7.5-8.**

Lustre. — Vitreous.

Color. — **Shades of green and blue**; also yellow, white, pink, and colorless.

Streak. — White.

**No cleavage. Conchoidal to uneven fracture.**

Brittle.

Transparent to translucent.

S. G. — 2.63-2.8.

B. B. — Infusible, but sometimes becomes cloudy.

Occurs crystalline or compact to granular massive, and in holohedral hexagonal crystals which are unstriated and often show a flat termination.

*Varieties.***EMERALD.***(Smaragdus.)*

Deep green, transparent material.

**AQUAMARINE.**

Beautiful greenish blue, transparent material. The name is also applied to stones that are blue without any tint of green.

**MORGANITE.**

Deep pink, transparent material.

Compare with Quartz (p. 69), Topaz (p. 179), and Tourmaline (p. 192).

The transparent material makes valuable gems.

See Fig. 54.

**353. IOLITE.**  $H_2 \left\{ \begin{smallmatrix} Mg \\ Fe \end{smallmatrix} \right\} Al_2 Si_2 O_{17}$ . Hardness 7-7.5.

(*Dichroite, Cordierite, Water Sapphire.*)

Lustre. — Vitreous to resinous.

Color. — **Light, dark, or smoky blue**; sometimes gray or yellow.

Streak. — White.

**No cleavage.** Sub-conchoidal fracture.

Brittle.

Transparent to translucent.

Dichroic. — Blue and yellow or colorless.

S. G. — 2.63.

B. B. — Practically infusible but may become opaque.

Usually occurs crystalline massive or as imbedded grains looking much like blue Quartz (p. 69); also in short, prismatic orthorhombic crystals.

Compare with Quartz (p. 69) and Nephelite (p. 161).

Occasionally cut as an ornamental stone.

**357. NEPHELITE.**  $(\text{Na}, \text{K})_2\text{Al}_2\text{Si}_2\text{O}_{10}$ . Hardness 5.5-6.  
(*Nepheline*.)

Lustre. — Vitreous to **greasy**.

Color. — **Greenish or bluish gray, reddish brown**, and sometimes white or colorless when in crystals.

Streak. — White.

Cleavage. — **Hexagonal prismatic, good to absent**.

Brittle. Sub-conchoidal to conchoidal fracture.

Transparent to nearly opaque.

S. G. — 2.55-2.65.

B. B. — Usually fuses easily to a colorless glass. Some of the massive varieties fuse with great difficulty, however.

Occurs cleavable or non-cleavable crystalline massive, as imbedded grains or short, hexagonal crystals usually showing only a prism and basal plane and yielding **square and six-sided cross-sections** perpendicular and parallel to the vertical axis. Sometimes occurs columnar massive.

*Variety.*

**ELAEOLITE.**

Massive, greasy lustered material.

Compare with Quartz (p. 69) and Iolite (p. 160).

**360. CANCRINITE.**  $H_2Na_6Ca(NaCO_3)_2Al_2(SiO_4)_8$ .  
Hardness 5-6.

Lustre. — Sub-vitreous or greasy.

Color. — **Yellow**, white, gray, green, blue, and reddish.

Streak. — White.

Cleavage. — Good hexagonal prismatic.

Transparent to translucent.

S. G. — 2.46.

**B. B. — Fuses very easily** with intumescence to a white  
blebby glass.

**Effervesces vigorously in hot dilute HCl.**

Occurs usually as imbedded grains or massive; rarely  
in prismatic hexagonal crystals.

**The fusibility and acid test are completely determinative.**

**362. SODALITE.**  $\text{Na}_4 \left\{ \begin{smallmatrix} \text{Al} \\ \text{Cl} \end{smallmatrix} \right\} \text{Al}_3\text{Si}_3\text{O}_{12}$ .      **Hardness 5.5-6.**

Lustre. — Vitreous or slightly greasy.

Color. — **Blue**, gray, greenish, yellowish, white.

Streak. — White.

Cleavage. — Poor to good dodecahedral.

Brittle. Conchoidal to uneven fracture.

Transparent to translucent.

S. G. — 2.14-2.30.

**B. B.** — Fine splinters are fairly easily fusible with intumescence, yielding a colorless glass.

Occurs massive and in disseminated grains; also in concentric nodular forms and, rarely, in holohedral isometric crystals.

Compare with Fluorite (p. 65) and Lazurite (p. 164).

**365. LAZURITE.**  $\text{Na}_4(\text{NaS}_3, \text{Al})\text{Al}_2(\text{SiO}_3)_3$ .**Hardness 5-5.5.***(Lapis Lazuli, Lapis, Native Ultramarine.)*

Lustre. — Vitreous to dull.

Color. — **Deep blue** to azure-blue, sometimes with a greenish or purplish tint.

Streak. — White.

Brittle. Uneven fracture.

Translucent to nearly opaque.

S. G. — 2.41.

B. B. — In forceps, fuses fairly easily with intumescence to a white glass.

Occurs as disseminated particles or in **compact masses which often contain particles of Pyrite** (p. 43), Calcite (p. 109), or other minerals. Dodecahedral or cubical crystals are rare.

Compare with Fluorite (p. 65), Azurite (p. 128), Sodalite (p. 163), Lazulite (p. 243), Vivianite (p. 244), Turquoise (p. 247), and Chalcanthite (p. 266).

Used as a gem and an ornamental stone.



369. **ZUNYITE.**  $(\text{Al} \begin{Bmatrix} \text{OH} \\ \text{F} \\ \text{Cl} \end{Bmatrix})_3 \cdot \text{Al}_2\text{Si}_2\text{O}_{13}$  Hardness 7.

Lustre. — Vitreous.

Color. — Colorless or white.

Streak. — White.

Cleavage. — Fair + and - tetrahedral.

Transparent to opaque.

S. G. — 2.87.

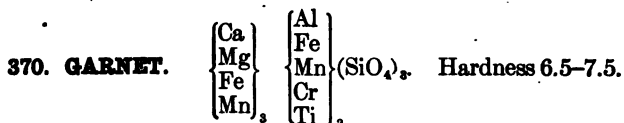
B. B. — **Infusible**, but becomes opaque and looks like porcelain.

Occurs in **small, sharply crystallized tetrahedrons, imbedded in a white, earthy rock**, or mixed with **GUITERMANITE**, a sulphide of As and Pb.

**The crystals are usually unmodified by any forms except sometimes a negative tetrahedron.**

Compare with Boracite (p. 251).

## GARNET GROUP.



Lustre. — Vitreous to resinous.

Color. — **Red, brown, yellow, white, black, green.**

Streak. — White.

Cleavage. — **None usually apparent.** Rarely, dodecahedral.

Brittle. Uneven fracture.

Transparent to opaque.

**Electrified when gently heated.**

S. G. — 3.1–4.3.

B. B. — All varieties but Uvarovite fuse fairly easily, **always fusing to a darker color than they were originally**, some becoming magnetic.

Occurs usually as more or less modified dodecahedral or trapezohedral isometric crystals imbedded in mica or other schists, the faces being often striated; also as druses, granular, lamellar or compact massive, and as rounded grains in alluvial material. Rarely tough and cryptocrystalline.

*Varieties.*

**GROSSULARITE** or **ESSONITE.** CaAl.

White, yellowish, yellowish brown, pale green, pale rose-red.

**PYROPE.** MgAl.

Deep red to nearly black. Sometimes yellowish. Often transparent and is then a semi-precious gem. Crystals rare.

**ALMANDITE.**  $\text{FeAl}$ .

Deep red, transparent, to brownish red or black, translucent to opaque. Often purplish. Includes both semi-precious and common Garnet. Apt to occur in crystals.

**SPESSARTITE.**  $\text{MnAl}$ .

Dark purplish red to brownish red.

**ANDRADITE.**  $\text{CaFe}$ .

Many colors but lacking transparency and including much of the common Garnet.

**UVAROVITE.**  $\text{CaCr}$ .

Emerald-green, infusible crystals.

Compare the massive material with massive Vesuvianite (p. 177), Chondrodite (p. 190), and Tourmaline (p. 192).

Garnet is a very important abrasive substance and many of the transparent varieties make beautiful, semi-precious gems.

See Fig. 55.

**371. SCHORLOMITE.**  $3\text{CaO} \cdot \left\{ \begin{smallmatrix} \text{Fe} \\ \text{Ti} \end{smallmatrix} \right\}_2 \text{O}_3 \cdot 3 \left\{ \begin{smallmatrix} \text{Si} \\ \text{Ti} \end{smallmatrix} \right\} \text{O}_2$ .  
 Hardness 7-7.5.

Lustre. — Vitreous.

Color. — **Black, often iridescently tarnished.**

Streak. — **Grayish black.**

**Conchoidal fracture.** Brittle.

Translucent to opaque.

S. G. — **3.8.**

B. B. — Fuses fairly easily and quietly to a black magnetic glass.

Occurs usually massive.

Compare with Allanite (p. 187) and Samarskite (p. 233).

**GARNET GROUP.**

*Members.* — Garnet, Schorlomite.

*Composition.* — Silicates of several bases.

*Crystallization.* — Holohedral isometric.

*Additional.* — Both have a vitreous lustre, a hardness of about 7, fuse in a similar manner, and are without cleavage.



FIG. 54. — Beryl, Chaffee County, Colorado.



FIG. 55. — Garnet (weight, 8 lbs.) Salida, Colorado.

**376. CHRYSOLITE.**  $\left\{ \begin{array}{c} \text{Mg} \\ \text{Fe} \end{array} \right\}_2 \text{SiO}_4$ . Hardness 6.5–7.  
*(Olivine, Job's Tears.)*

Lustre. — Vitreous.

Color. — **Bottle-green.** By oxidation of the Fe becomes very dark green or reddish brown and dull lustred. Yellow-green when fine grained.

Streak. — White or yellowish.

**No cleavage. Conchoidal fracture.** Brittle.

**Transparent;** opaque when the Fe has oxidized.

S. G. — 3.27–3.37.

B. B. — Usually infusible, but loses color.

Occurs in coarse to fine **granular masses**, as disseminated grains, and, rarely, as rectangular orthorhombic crystals or as sand.

*Variety.*

### **PERIDOT or EVENING EMERALD.**

Yellowish green transparent material which, when cut and polished, forms a semi-precious gem.

Compare with Willemite (p. 171) and Epidote (p. 186).

Large grains or crystals without flaws are valuable gem material.

**PHENACITE GROUP.**

**381. WILLEMITE.**  $\text{Zn}_2\text{SiO}_4$ . Hardness 5.5.

Lustre. — Weak vitreous or resinous to dull.

Color. — Green or yellow when pure, but often brown or flesh colored.

Streak. — White or grayish.

Cleavage. — Poor hexagonal prismatic to none.

Brittle. Conchoidal to uneven fracture.

Transparent to opaque.

S. G. — 3.89–4.18.

B. B. — Glows and fuses with difficulty on the edges to a white enamel. On charcoal, gives sublimate of zinc oxide after long heating.

Usually occurs **granular** or in rather **thick, prismatic, rhombohedral hemihedral hexagonal crystals**; rarely massive. The crystals are rarely long and slender.

Often associated with **Zincite** (p. 81), **Franklinite** (p. 92), **Calcite** (p. 109), and **Rhodonite** (p. 151).

*Variety.*

**TROOSTITE.**

Thick prismatic, gray or flesh colored crystals.

Compare with **Rhodonite** (p. 151), **Wernerite** (p. 175), and **Apatite** (p. 235).

A valuable ore of Zinc.

**382. PHENACITE.**  $\text{Be}_3\text{SiO}_4$ .**Hardness 7.5-8.**

Lustre. — Vitreous.

Color. — **Colorless**, white, yellow, pink, or brown.

Streak. — White!

Brittle. Conchoidal fracture.

Transparent to translucent.

S. G. — 2.98.

B. B. — Becomes dull blue when moistened with dilute cobalt nitrate and heated. Infusible.

Occurs in **rhombohedral tetartohedral hexagonal crystals**, which are **often tabular** in habit. Associated with Amazon Stone (p. 135), Smoky Quartz (p. 70), Beryl (p. 159), Chrysoberyl (p. 95), Topaz (p. 179), etc.

Compare with Quartz (p. 69), Beryl (p. 159), and Topaz (p. 179).

Occasionally used as a gem.



**PHENACITE GROUP.**

*Members.* — Willemite, Phenacite.

*Composition.* — Silicates.

*Crystallization.* — Rhombohedral hemihedral and tetartohedral hexagonal.

*Additional.* — Both are relatively hard, have a light streak, and may have a vitreous lustre.

**SCAPOLITE GROUP.**

**386. MEIONITE.**  $\text{Ca}_4\text{Al}_6\text{Si}_6\text{O}_{28}$ . Hardness 5.5–6.

Lustre. — Vitreous.

Color. — **Colorless or milky white.**

Streak. — White.

Cleavage. — Prismatic at angle of  $90^\circ$ , good to absent.

Brittle. Conchoidal fracture.

**Transparent** to translucent.

S. G. — 2.72.

B. B. — Fuses easily with intumescence to a white blebby glass.

Occurs in pyramidal hemihedral **tetragonal crystals** which are usually apparently holohedral; also in crystalline grains and massive.

Compare with Pyroxene (p. 146) and Wernerite (p. 175).

**387. WERNERITE.**  $\text{Na}_2\text{Ca}_2\text{Al}_4\text{Si}_4\text{O}_{14}$ . Hardness 5-6.  
(*Scapolite*.)

**Lustre.** — Vitreous to dull, the latter being often confined to the outside.

**Color.** — White, gray, lilac, greenish, and other light tints.

**Streak.** — White.

**Cleavage.** — Poor to good, parallel to direct and indirect tetragonal prisms.

**Brittle.**

**Translucent to opaque.**

**S. G.** — 2.7.

**B. B.** — Fuses easily with intumescence to a white blebby glass.

Occurs as large, dull tetragonal crystals that are really pyramidal hemihedral but are usually apparently holohedral; also cleavable, columnar or granular massive.

Cleavage or crystal surface often shows a characteristic fibrous appearance.

Compare with Orthoclase (p. 132), Pyroxene (p. 146), Spodumene (p. 148), and Meionite (p. 174).

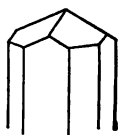


FIG. 56.

**SCAPOLITE GROUP.**

*Members.* — Meionite, Wernerite.

*Composition.* — Calcium Aluminum silicates, with or without Sodium.

*Crystallization.* — Pyramidal hemihedral tetragonal.

*Additional.* — Both may have a vitreous lustre, a hardness of between 5 and 6 and both fuse in a similar manner.

**393. VESUVIANITE.**  $H_4Ca_{12}\left\{\begin{smallmatrix} Al \\ Fe \end{smallmatrix}\right\}_2Si_{10}O_{42}$ . Hardness 6.5.  
(*Idocrase.*)

Lustre. — Vitreous to resinous.

Color. — **Brown, green,** and, rarely, yellow or pale blue.

Streak. — White.

Cleavage. — **None.**

Brittle. Uneven to sub-conchoidal fracture.

Nearly transparent to opaque.

S. G. — 3.35–3.45.

**B. B.** — Fuses easily with intumescence to a **green or brown glass.**

Occurs usually in pyramidal tetragonal crystals; or as deeply striated or grooved crystalline aggregates; also radiating, columnar, granular, and compact massive.

### CALIFORNITE.

Translucent, cryptocrystalline material, yellowish to emerald-green or gray spotted with green.

Compare massive material with Garnet (p. 166) and Tourmaline (p. 192).

Compare Californite with Jade (p. 154).

Californite and transparent, phenocrystalline material are used as gems.

**394. ZIRCON.**  $\text{ZrSiO}_4$ .

Hardness 7.5.

Lustre. — Adamantine to vitreous.

Color. — Usually gray or brown when opaque, and red when transparent; also yellow and green.

Streak. — White.

Cleavage. — None.

Brittle. Conchoidal fracture.

Opaque to transparent.

S. G. — 4.2–4.86.

B. B. — Infusible, but entirely loses color.

Occurs usually as small, sharply cut tetragonal crystals with a prism and rather flat pyramid of the same order as the main forms; also as highly modified crystals, irregular forms, and in grains.

*Varieties.***HYACINTH or JACINTH.**

Transparent, red, orange, or brown gem material.

**JARGON or JARGOON.**

Transparent, light-colored, more or less smoky material sometimes used as a substitute for Diamond (p. 1) when white.

The appearance is usually distinctive.

A semi-precious gem when transparent and of good color. Zirconium oxide may be used as a substitute for lime in the oxy-hydrogen lantern.



FIG. 57.

## TOPAZ GROUP.

**397. TOPAZ.**  $(\text{Al}\left\{\begin{smallmatrix} \text{O} \\ \text{F}_2 \end{smallmatrix}\right\})\text{AlSiO}_4$

**Hardness 8.**

Lustre. — **High vitreous** to adamantine.

Color. — **White, yellow, yellowish brown** or light tints of blue, green or pink.

Streak. — **White.**

Cleavage. — **Basal, very perfect** to fair in some massive varieties.

Brittle.

Transparent to translucent.

**Electrified when gently heated.**

S. G. — **3.4-3.65.**

B. B. — **Infusible**, but some yellow varieties become pink or reddish.

Occurs in **fine, prismatic orthorhombic crystals** which are often highly modified; also cleavable massive and as water-worn pebbles in alluvial material; rarely granular.

Sometimes the crystals are rough and almost opaque due to inclusions of the gangue-rock.

The colored varieties often lose their color when exposed to the light.

Compare with Quartz (p. 69), Beryl (p. 159), and Tourmaline (p. 192).

Is used to some extent as an abrasive and the transparent varieties are cut for gems, the white material being a substitute for Diamond (p. 1).



**FIG. 58.**

**393. ANDALUSITE.**  $\text{Al}_2\text{SiO}_5$ .

Hardness 7.5.

Lustre. — Vitreous, often weak.

Color. — Usually **brownish red** or **pearl-gray**; sometimes whitish, violet, and dull green.

Streak. — White.

Cleavage. — Poor to good prismatic at angle of  $89^\circ 12'$ .

Brittle to tough.

Transparent to opaque. Usually translucent.

S. G. — 3.18.

B. B. — Infusible.

Occurs in **coarse, nearly square, prismatic orthorhombic crystals**, or tough, indistinctly columnar or granular massive.

*Variety.***CHIASTOLITE or MACLE.**

An impure, soft, dull, hydrated variety occurring in **rounded prisms which exhibit on cross-section a white cross or other symmetrical design on a dark ground**, caused by the inclusion of organic impurities during the crystallization process.

Compare with Elaeolite (p. 161) and Wernerite (p. 175).



FIG. 59.  
Sections of Chiasolite.



**399. SILLIMANITE.**  $\text{Al}_2\text{SiO}_5$ .

Hardness 6-7.

*(Fibrolite.)*

Lustre. — Vitreous, high to dull.

Color. — **Brown, gray,** and sometimes greenish.

Streak. — White.

Cleavage. — **Perfect brachy-pinacoidal,** often indistinct on fibrous varieties.**Usually very tough.**

Transparent to translucent.

S. G. — 3.23.

B. B. — Infusible.

Occurs in **very long and slender, indistinctly terminated orthorhombic crystals**; also columnar or fibrous massive, being sometimes very compact.

Compare with Tremolite (p. 153), Andalusite (p. 180), and Cyanite (p. 182).

The densely compact, fibrous variety was much used for making implements and weapons during the "Stone Age," being almost as tough as Jade (p. 154).

**400. CYANITE.**  $\text{Al}_2\text{SiO}_5$ .**Hardness 4-7.**

(See below.)

*(Kyanite, Disthene.)*Lustre. — Vitreous to **pearly on cleavage face.**Color. — **White or light blue**; sometimes gray, green or black. **The white material is very often streaked with blue.**Cleavage. — **Perfect macro-pinacoidal**, a fair brachy-pinacoidal at an angle of  $73^\circ 56'$  with the first, and a basal parting at an angle of  $78^\circ 30'$  with the first and at an angle of  $86^\circ 45'$  with the second. The last two often appear as cracks on the perfect cleavage.

Brittle.

Transparent to translucent.

S. G. — 3.56–3.67.

B. B. — Infusible.

Occurs in long, bladed triclinic crystals; sometimes fibrous.

**The hardness is 4-5 on the cleavage face parallel to the direction of elongation and 6-7 perpendicular to this direction.****The appearance and hardness test are usually perfectly distinctive.**

The transparent varieties are sometimes used as gems, the blue material resembling Sapphire (p. 84).

See Fig. 60.

**TOPAZ GROUP.**

*Members.* — Topaz, Andalusite, Sillimanite, Cyanite.

*Composition.* — All have the formula  $\text{Al}_2\text{SiO}_5$ , but Topaz contains some Fluorine.

*Crystallization.* — Orthorhombic and triclinic.

*Additional.* — Only Cyanite can be scratched with a knife, and that is possible in only one direction on this mineral.  
All may have a vitreous lustre and are infusible.



FIG. 60. — Cyanite, St. Gothard Region, Switzerland.

**401. DATOLITE.**  $\text{Ca}(\text{BOH})\text{SiO}_4$ .      **Hardness 5.-5.5.**  
(*Datholite.*)

Lustre. — Vitreous to dull.

Color. — **Colorless**, white or greenish when in crystals;  
greenish, reddish or yellowish when massive.

Streak. — White.

Cleavage. — **None.**

Brittle. Conchoidal to uneven fracture.

Transparent to opaque.

S. G. — 2.9-3.

B. B. — Fuses very easily with intumescence to a clear glass, yielding B flame.

Occurs as **groups of very complex, glassy monoclinic crystals** lining cavities in "Trap" rocks; also **cryptocrystalline or flint-like**; rarely botryoidal with a radiating structure.

**The lack of cleavage or the hardness will serve to distinguish this from all similar species.**

**406. ZOISITE.**  $\text{HCa}_2\text{Al}_2\text{Si}_2\text{O}_{10}$ .

Hardness 6-6.5.

Lustre. — Vitreous.

Color. — **Gray or pink**; sometimes brown or green.

Streak. — White.

Cleavage. — **Perfect brachy-pinacoidal.**

Brittle.

Transparent to translucent.

S. G. — 3.25-3.37.

B. B. — Swells and fuses to a white, blebby glass.

Occurs in deeply vertically striated or furrowed orthorhombic crystals which rarely show distinct terminations; also compact to **cleavable, columnar massive**; sometimes almost fibrous or cryptocrystalline.

*Varieties.***THULITE.**

Pink in color and often almost fibrous in structure.

**.SAUSSURITE.**

A dull, tough, compact, cryptocrystalline mixture of several minerals, being principally Zoisite with more or less Albite (p. 137), Epidote (p. 186), Calcite (p. 109), Garnet (p. 166), Tremolite (p. 153), Chlorite (p. 215), etc. It is gray or greenish in color and results from the alteration of Plagioclases in basic, eruptive rocks.

Compare with Tremolite (p. 153).

**407. EPIDOTE.**  $\text{HCa}_2\left\{\begin{smallmatrix} \text{Al} \\ \text{Fe} \end{smallmatrix}\right\}_3 \text{Si}_3\text{O}_{13}$ . Hardness 6-7.

Lustre. — Vitreous to dull.

Color. — **Pistachio-green** when massive and **dark green** to greenish black or brown when in crystals; very rarely red, gray or colorless.

Streak. — White.

Cleavage. — **Perfect basal.**

Brittle.

Transparent to opaque.

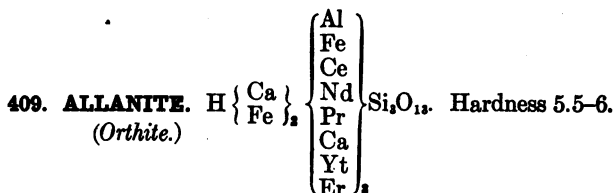
**Dichroic. — Brown and green.**

S. G. — 3.25-3.50.

B. B. — Fuses fairly easily with intumescence to a dark brown or black glass which is sometimes magnetic.

Occurs in **monoclinic crystals, often long, brilliant, deeply striated**, and elongated in the direction of the ortho-axis. The crystals are frequently so twinned (parallel to the ortho-pinacoid) as to appear orthorhombic. The mineral also occurs **coarse cleavable to fine granular** and, rarely, fibrous.

Compare with Chrysolite (p. 170) and Willemite (p. 171).



Lustre. — **Sub-metallic** to pitch-like.

Color. — **Brown to black.**

Streak. — **Nearly white**; also gray and tinted.

Cleavage. — None. **Uneven fracture.**

Brittle.

Opaque.

S. G. — 3.5-4.2.

B. B. — Swells and fuses easily to a dark, blebby, magnetic glass.

Occurs in veins and massive, or as round to angular disseminated grains; also in tabular to acicular monoclinic crystals. Often **associated with a yellow or yellowish brown earthy substance**, largely Limonite (p.104).

Compare with Schorlomite (p 168) and Samarskite (p. 232).

410. **AXINITE.**  $\text{HCa}_2 \left\{ \begin{smallmatrix} \text{Fe} \\ \text{Mn} \\ \text{Mg} \end{smallmatrix} \right\} \text{BaAl}_2(\text{SiO}_4)_4$ . Hardness 6.5–7.

Lustre. — High vitreous.

Color. — **Olive-brown**, dark blue, or gray; sometimes yellow or greenish.

Streak. — White.

Brittle. Conchoidal fracture.

**Transparent** to sub-translucent.

Pleochroic. — Green, blue, and brown.

S. G. — 3.28.

B. B. — Fuses very easily with intumescence to a dark green or black glass, yielding B flame during fusion.

Occurs usually in **acute-edged, tabular triclinic crystals**, often coated with Chlorite (p. 215); rarely massive, lamellar or granular.

Compare with Titanite (p. 229).

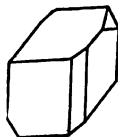


FIG. 61.



411. **PREHNITE.**  $H_2Ca_2Al_2Si_2O_{12}$ . Hardness 6–6.5.  
(*Cape Chrysolite.*)

Lustre. — Vitreous.

Color. — **Light green** to grayish.

Streak. — White.

Cleavage. — Good basal.

Brittle.

Translucent.

S. G. — 2.8–2.95.

B. B. — Fuses very easily to a blebby, enamel-like glass.

Occurs in **botryoidal or globular groups of tabular orthorhombic crystals**, united by their basal-pinacoids and **forming a crust or lining to cavities** in "Trap" rocks. These groups are often rounded or barrel-shaped and have a radiating structure. Rarely found compact granular.

Often associated with Zeolites (p. 196), Datolite (p. 184), and Calcite (p. 109) or Aragonite (p. 120).

Compare with Chalcedony (p. 72), Smithsonite (p. 117), and Calamine (p. 191).

Prehnite takes a high polish and is used for inlaid work and for making ornaments. It has been used occasionally as a gem.

**415. CHONDRODITE.**  $H_2 \left\{ \begin{smallmatrix} Mg \\ Fe \end{smallmatrix} \right\}_{19} Si_3O_{24}F_4$ . Hardness 6–6.5.

Lustre. — Vitreous.

Color. — **Garnet-red**, reddish brown, yellowish brown or yellow.

Streak. — White.

Cleavage. — Practically none. Uneven fracture.

Brittle.

Transparent to translucent.

S. G. — 3.1–3.2.

B. B. — **Infusible**, but sometimes blackens and then turns white.

Occurs in **very complex monoclinic crystals**, compact massive, and as disseminated grains.

Usually found in crystalline Limestones or associated with Serpentine (p. 219) — formed by alteration of the Chondrodite —, Magnetite (p. 91), and Chlorite (p. 215).

Compare with Garnet (p. 166) and Tourmaline (p. 192).

**423. CALAMINE.**  $\text{H}_2\text{Zn}_2\text{SiO}_6$ .**Hardness 4.5-5.***(Electric Calamine.)*

Lustre. — Vitreous to nearly pearly.

Color. — Colorless or white, often tinted with yellow or brown; rarely bluish or greenish.

Streak. — White.

Cleavage. — Good prismatic at angle of  $103^\circ 51'$ .

Brittle.

Transparent to opaque.

S. G. — 3.4-3.5.

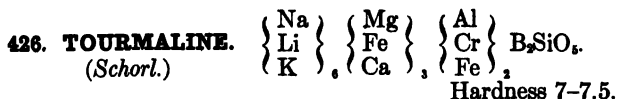
B. B. — Infusible.

Usually occurs as a drusy coating of more or less transparent, hemimorphic orthorhombic crystals, usually united to form ridges or cockscombs showing transverse grooves; also stalactitic, botryoidal, granular massive, and as a constituent of clays. Crusts have a coarsely radiating structure.

The hardness and manner of occurrence are usually distinctive, though it sometimes closely resembles Smithsonite (p. 117) and, less closely, Prehnite (p. 189).

It is a fairly common and valuable ore of Zinc, requiring no roasting but sometimes being calcined in kilns to drive off water.

**FIG. 62.**



Lustre. — Vitreous to resinous.

Color. — **Black, brown, brownish red, red, green, and, rarely, blue; sometimes the color of the interior differs from that of the exterior or the two ends of a crystal are of different colors.**

Streak. — White.

Cleavage. — **None.**

Very brittle. Uneven to sub-conchoidal fracture.

Transparent to opaque.

**Strongly electrified when gently heated.**

Dichroic; dark and light shades.

S. G. — 2.98-3.02.

B. B. — **Usually fuses, either easily or with difficulty, to a glass, sometimes blebby and always lighter in color than the unfused mineral.**

Occurs in prismatic or, rarely, flattened, indistinct or sharply crystallized hemimorphic rhombohedral hemihedral hexagonal crystals, which usually show a spherical triangle in cross-section and are often vertically striated.

The forms common on crystals are a trigonal prism of the first order, a second order prism, + R and -  $\frac{1}{2}$  R, rarer forms being other rhombohedrons, scalenohedrons, basal pinacoid, ditrigonal prisms, and a - trigonal prism of the first order.

Occurs also compact massive and coarse to fine columnar, parallel or radiating.

#### *Varieties.*

#### *Alkali Tourmaline.*

Color red (**RUBELLITE**), green (**BRAZILIAN EMERALD, CHRYSOLITE, or PERIDOT; CEYLON PERIDOT**), blue (**INDICOLITE, BRAZILIAN SAPPHIRE**), or white (**ACHROITE**).

*Iron Tourmaline.*

Color usually black. May not be electrified by heat.

*Magnesium Tourmaline.*

Color reddish brown to brownish black or, rarely, colorless.

The manner of occurrence or the B. B. reactions are distinctive, though Tourmaline often closely resembles Garnet (p. 166), Vesuvianite (p. 177) or Chondrodite (p. 190) when massive, and Actinolite (p. 153), Hornblende (p. 154) or Beryl (p. 159) when crystallized.

The colored, transparent varieties are cut, and rank as semi-precious gems.

See Fig. 66.

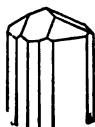


FIG. 63.



FIG. 64.

**428. STAUROLITE.**  $H_4 \left\{ \begin{smallmatrix} Fe \\ Mg \end{smallmatrix} \right\}_6 \left\{ \begin{smallmatrix} Al \\ Fe \end{smallmatrix} \right\}_{24} Si_{11}O_{66}$

Hardness 7-7.5.

Lustre. — Vitreous to dull.

Color. — **Reddish brown or yellowish.**

Streak. — White or gray.

Cleavage. — **None.**

Brittle. Uneven to sub-conchoidal fracture.

Translucent to **opaque.**

S. G. — 3.65-3.75.

B. B. — Usually infusible. A rare magnesian variety fuses easily to a black, magnetic glass.

Occurs always as **simple or twinned orthorhombic crystals**, the twins being cruciform and crossing at angles of 90° or 120°.

The forms present are usually a wide angled prism; brachy-pinacoid, basal-pinacoid, and macro-dome. By suppression of opposite dome faces, the crystals often appear to be monoclinic.

**Usually found imbedded in mica or other schists.**

**The appearance is distinctive.**

See Fig. 67.

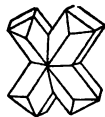


FIG 65.  
Cross Twins.



**FIG. 66.**—Tourmaline, California.



**FIG. 67.**—Staurolite, St. Gothard Region, Switzerland.

## HYDROUS SILICATES.

## ZEOLITE DIVISION.

**435. APOPHYLLITE.**  $H_7KCa_4(SiO_3)_8 + 4\frac{1}{2} H_2O$ .

Hardness 4.5–5.

Lustre. — Vitreous. **Pearly on cleavage face.**

Color. — **Colorless or white**; sometimes pink, and, rarely, greenish or yellowish.

Streak. — White.

Cleavage. — **Perfect basal.**

Brittle.

Transparent to nearly opaque.

S. G. — 2.3–2.4.

B. B. — Exfoliates and fuses very easily to a white blebby enamel, yielding K flame.

Occurs in **distinct prismatic, cubical, or tabular tetragonal crystals**. The prismatic habit usually shows a prism and pyramid of different orders. In all habits the **prism is vertically striated**. Other forms may be present, the basal-pinacoid being prominent on the second and third habits and often appearing as a cleavage face on the first habit. Found also massive and lamellar; rarely radiated concentric.

Compare with Chabazite (p. 199).



FIG. 68.



**438. HEULANDITE.**  $H_4CaAl_2Si_6O_{18} + 3H_2O$ . Hard-  
ness 3.5–4.

Lustre. — Vitreous. **Pearly on cleavage face.**

Color. — **White**, yellow, brown, red.

Streak. — **White.**

Cleavage. — **Perfect clino-pinacoidal.**

Brittle.

Transparent to translucent.

S. G. — 2.2.

B. B. — Exfoliates and fuses very easily to a white enamel.

Occurs in **monoclinic crystals** and, rarely, globular or granular.

Crystals are often made up of many individuals flattened parallel to the clino-pinacoid and attached in nearly parallel position.

The appearance of a **cleavage face is unsymmetrical**, as shown below.

Compare with Stilbite (p. 198) and Gypsum (p. 264).



**FIG. 69.**  
**Cleavage Face.**

**443. STILBITE.**  $H_4 \left\{ \begin{smallmatrix} Ca \\ Na_2 \end{smallmatrix} \right\} Al_2Si_6O_{18} + 4H_2O.$  Hard-  
(*Desmine.*) ness 3.5-4.

Lustre. — Vitreous. **Pearly on cleavage face.**

Color. — **White, yellow, red, brown.**

Streak. — **White.**

Cleavage. — **Perfect clino-pinacoidal.**

Brittle.

Transparent to translucent.

S. G. — 2.1-2.2.

**B. B.** — Exfoliates and fuses very easily to a white enamel.

Occurs in **single, usually tabular, pseudo-orthorhombic monoclinic crystals or united parallel to the clino-pinacoid into sheaf-like bunches.** Crystals are always complex twins. Found also radiated, globular, and lamellar or columnar.

The appearance of a cleavage face is symmetrical, as shown below.

Compare with Heulandite (p. 197) and Gypsum (p. 264).

See Fig. 71.



**FIG. 70.**  
**Cleavage Face.**

**447. OHABAZITE.**  $\left\{ \begin{array}{c} \text{Ca} \\ \text{Na}_2 \\ \text{K}_2 \end{array} \right\} \text{Al}_2\text{Si}_4\text{O}_{12} + 6\text{H}_2\text{O}.$  Hard-  
ness 4-5.

Lustre. — Vitreous.

Color. — **Light red, white, yellow, colorless.**

Streak. — White.

Cleavage. — Poor rhombohedral.

Brittle.

Transparent to translucent.

S. G. — 2.12.

**B. B.** — Intumesces and fuses easily to a white blebby glass.

Occurs usually in **unmodified rhombohedrons, closely resembling cubes** (R to R being  $85^\circ 14'$ ), **often striated parallel to the edges.** Interpenetration or contact twins with the basal-pinacoid as twinning plane are not uncommon. More or less modified crystals and twinning parallel to the rhombohedron are rare.

**The first material to deposit in cavities in basic lavas.**

### *Variety.*

### **PHACOLITE.**

Colorless crystals which show contact twinning parallel to the basal pinacoid and are usually rather highly modified so as to be rather lenticular in form.

Compare with Calcite (p. 109) and Apophyllite (p. 196).

See Fig. 72.

**450. ANALCITE.**  $\text{NaAlSi}_3\text{O}_8 + \text{H}_2\text{O}$ . Hardness 5-5.5.

Lustre. — Vitreous.

Color. — **White**, colorless; rarely greenish or reddish.

Streak. — White.

Cleavage. — Practically none.

Brittle. Sub-conchoidal fracture.

Transparent to opaque.

S. G. — 2.25.

B. B. — Fuses easily and quietly to a colorless glass.

Occurs usually as **unmodified isometric trapezohedrons**, commonly forming a rather drusy surface and only very **rarely bounded on all sides by faces** like Leucite (p. 143).

Sometimes modified by the trisoctohedron, and very rarely cubical in habit.

Also found granular to compact massive.

Usually **forms after, and on top of Thomsonite** (p. 203) **in cavities in basic lavas**.

Compare crystals with Leucite (p. 143) and Garnet (p. 166).

Compare massive material with Quartz (p. 69).

See Fig. 73.

**453. NATROLITE.**  $\text{Na}_2\text{Al}_2\text{Si}_8\text{O}_{10} + 2\text{H}_2\text{O}$ .

(Needle Zeolite.)

Hardness 5-5.5.

Lustre. — Vitreous.

Color. — **Colorless, white**; rarely yellow or reddish.

Streak. — White.

Cleavage. — Good prismatic at angle of  $88^\circ 45'$ .

Brittle.

Transparent to translucent.

S. G. — 2.22.

B. B. — Fuses very easily and quietly to a colorless glass.

Occurs in **slender orthorhombic crystals showing a nearly square prism, a flat pyramid, and often a brachypinacoid**. These are usually interlacing or divergent. Also found fibrous, and, rarely, massive.

Compare with Pectolite (p. 150), Mesolite (p. 202), and Thomsonite (p. 203).

**455. MESOLITE.**  $\left\{ \begin{smallmatrix} \text{Ca} \\ \text{Na}_2 \end{smallmatrix} \right\} \text{Al}_2\text{Si}_2\text{O}_{10} + 3\text{H}_2\text{O}$ . Hardness 5.

Lustre. — **More or less silky** to vitreous.

Color. — **White**, colorless, grayish, yellowish.

Streak. — **White**.

Cleavage. — **Good prismatic** at angle of  $88^\circ$  but this is only apparent on crystals.

Crystals are brittle, fibrous material is flexible, and the cryptocrystalline variety is tough.

Transparent to opaque.

S. G. — 2.2–2.4.

B. B. — **Becomes opaque, swells into vermicular forms, and fuses easily to a blebby enamel.**

**Occurs in very delicate, cotton-like, fibrous, divergent groups or tufts or as interlaced fibres, being usually the last substance to form in cavities in basic lavas.**

Also, but rarely, found in slender, prismatic monoclinic or triclinic crystals; as silky fibrous or columnar nodules or masses; stalactitic with a radiating fibrous structure; massive; porcelain-like cryptocrystalline.

Compare with Pectolite (p. 150), Natrolite (p. 201), and Thomsonite (p. 203).

See Fig. 74.



Hardness 5-5.5.

Lustre. — Vitreous.

Color. — **Snow-white**, reddish, greenish, brown.

Streak. — White.

Cleavage. — **Perfect brachy-pinacoidal.**

Rather brittle.

Transparent to nearly opaque.

S. G. — 2.3-2.4.

B. B. — Fuses easily with intumescence to a white enamel.

Occurs in **hard, botryoidal crusts, globular or stalactitic with a radiating structure**; also in **radiating, globular aggregates of platy orthorhombic crystals**; sometimes compact, filling cavities in igneous rock. The last variety has a structure which radiates from one or several centers and is mottled or banded with red and green. Weathering washes these amygdules out of the rock and they are then found in the form of pebbles.

Compare the crystalline material with Pectolite (p. 150) and Natrolite (p. 201).

Compare the amygdaloidal variety with Agate (p. 74).

The amygdaloidal variety is a semi-precious stone.

See Figs. 73, 74, and 75.

**ZEOLITE DIVISION.**

*Members.* — Apophyllite, Heulandite, Stilbite, Chabazite, Analcite, Natrolite, Mesolite, Thomsonite.

*Composition.* — Hydrous silicates of aluminum and one or more of the elements calcium, sodium and potassium.

*Crystallization.* — All systems.

*Additional.* — All fuse easily and most of them intumesce or exfoliate. All are under six in hardness and are apt to be white.

Zeolites are all formed by the alteration of the Plagioclases in basic eruptive rocks, occurring in cavities in the same.

The lining of a cavity — the first mineral formed — is often Chabazite. On this occurs a layer of Thomsonite, then, often, some Analcite or other species.



FIG. 71. — Stilbite, New Jersey.





**FIG. 72.**—Chabazite, Nova Scotia.



**FIG. 73.**—Analcite on Thomsonite,  
North Table Mountain, Golden, Colorado.



**FIG. 74.** — Mesolite on Thomsonite,  
North Table Mountain, Golden, Colorado.



**FIG. 75.** — Thomsonite,  
North Table Mountain, Golden, Colorado.

## MICA DIVISION.

## MUSCOVITE GROUP.

**458. MUSCOVITE.**  $H,KAl_3Si_3O_{12}$ .      **Hardness 2-2.5.**  
(*Isinglass. Potash Mica.*)

**Lustre.** — Vitreous to pearly on cleavage face.

**Color.** — Colorless or light tints of nearly any color, particularly gray, brown or green.

**Streak.** — White.

**Cleavage.** — Perfect basal.

**Cleavage lamellae** are flexible, elastic, and transparent.

**Usually very tough.**

**S. G.** — 2.76-3.

**B. B.** — Practically infusible.

Occurs usually in disseminated scales, plates or scaly massive; also in masses of coarse to fine scales grouped in star-like, globular or plume-like forms; sometimes cryptocrystalline. Also found in tabular, horizontally striated monoclinic crystals which very closely resemble steep rhombohedrons and a basal plane.

Compare with Brucite (p. 107), Talc (p. 222), and Gypsum (p. 264).

Large plates are in demand for putting in stove doors, etc. Also much used as insulation in electrical apparatus and for spangling papers and fabrics.

**460. LEPIDOLITE.**  $\text{KLi} \left\{ \begin{array}{c} \text{Al}(\text{OH})_2 \\ \text{AlF}_2 \end{array} \right\} \text{Al}(\text{SiO}_3)_2$ .  
*(Lithia Mica.)* **Hardness 2.5-4.**

**Lustre.** — Pearly.

**Color.** — Usually pink or lilac; more rarely violet, gray, yellowish or white.

**Streak.** — White.

**Cleavage.** — Perfect basal.

**Cleavage lamellae** are flexible and elastic.

**Sectile.**

**Translucent.**

**S. G.** — 2.8-2.9.

**B. B.** — Fuses easily with intumescence to a white or grayish glass, yielding Li flame at the moment of fusion.

Occurs usually coarse to fine scaly-granular massive; sometimes in plates or in short, pseudo-hexagonal, monoclinic, prismatic crystals.

Compare with Diaspore (p. 101).

- 462. BIOTITE.**  $\left\{ \begin{smallmatrix} \text{H} \\ \text{K} \end{smallmatrix} \right\}, \left\{ \begin{smallmatrix} \text{Mg} \\ \text{Fe} \end{smallmatrix} \right\}, \text{Al}_2\text{Si}_2\text{O}_{12}$ . **Hardness 2.5-3.**  
*(Black Mica, Magnesium Mica.)*

**Lustre.** — **Pearly on cleavage face;** otherwise vitreous;  
 sub-metallic when black.

**Color.** — **Black or dark brown;** rarely dark green.

**Streak.** — White.

**Cleavage.** — **Perfect basal.**

**Very thin cleavage lamellae are flexible and elastic except-**  
 ing when hydrated, being then somewhat brittle.

**Sectile.**

**Transparent to opaque.**

**S. G.** — 2.7-3.1.

**B. B.** — Whitens and fuses on thin edges.

Occurs like Muscovite (p. 207), q. v.

Compare with Phlogopite (p. 210) and Jefferisite (p. 217).

**462A. PHLOGOPITE.**  $\left\{ \begin{array}{c} \text{H} \\ \text{K} \\ \text{MgF} \end{array} \right\} \text{Mg}_3\text{Al}(\text{SiO}_4)_3$   
*(Amber Mica.)* Hardness 2.5-3.

Lustre. — **Bronzy** to pearly on cleavage face.

Color. — **Yellowish brown** to **brownish red** or nearly black.

Streak. — **White.**

Cleavage. — **Perfect basal.**

**Thin cleavage lamellae** are flexible, elastic, and tough.

Sectile.

Transparent to translucent.

Thin laminae sometimes exhibit a six- or twelve-rayed star by transmitted light.

S. G. — 2.71.

B. B. — Whitens and fuses on thin edges.

Occurs in large or small, **tapering, prismatic, pseudo-hexagonal, monoclinic crystals** with a **six-sided** or **rhombic cross-section**; rarely tabular.

Compare with Biotite (p. 209) and Jefferisite (p. 217).

Is used as an insulating material in electrical apparatus.

**MUSCOVITE GROUP.**

*Members.* — Muscovite, Lepidolite, Biotite, Phlogopite.

*Composition.* — Hydrous silicates of aluminum and other bases.

*Crystallization.* — Monoclinic, pseudo-hexagonal.

*Additional.* — All are comparatively soft with a very perfect basal cleavage, and the cleavage lamellae are flexible and elastic and may show a pearly lustre.

**BRITTLE MICA GROUP.**

**464. MARGARITE.**  $H_2CaAl_4Si_4O_{18}$ .      **Hardness 3.5-4.5.**

**Lustre.** — Vitreous to **pearly on cleavage face.**

**Color.** — **Pink**, gray, yellow or white.

**Streak.** — White.

**Cleavage.** — **Perfect basal.**

**Cleavage lamellae** are brittle.

Translucent to nearly opaque.

S. G. — 3.03.

B. B. — Whitens and fuses on thin edges.

Occurs usually in intersecting or aggregated laminae; sometimes scaly massive, and very rarely in tabular, pseudo-hexagonal, monoclinic crystals.

**Often associated with Corundum (p. 83) and Diaspore (p. 101).**

Compare with Diaspore (p. 101), Muscovite (p. 207), and Lepidolite (p. 208).



**466. OHLORETOID.  $H_2(Fe,Mg)Al_2SiO_7$ . Hardness 6.5.**

Lustre. — High sub-metallic or slightly pearly on cleavage face.

Color. — **Dark greenish black, grayish black or greenish gray.**

Streak. — White, grayish or greenish.

Cleavage. — **Good basal.**

**Cleavage plates are brittle.**

Opaque to translucent in thin plates.

S. G. — 3.54.

**B. B. — Becomes darker and magnetic but is practically infusible.**

Occurs usually in cleavable, coarsely foliated masses; also as disseminated plates or scales and, rarely, as tabular, pseudo-hexagonal monoclinic or triclinic crystals.

**The cleavage, hardness, and brittleness will suffice to distinguish this from all similar minerals.**

**BRITTLE MICA GROUP.**

*Members.* — Margarite, Chloritoid.

*Composition.* — Hydrous silicates of aluminum and other bases.

*Crystallization.* — Monoclinic or triclinic, pseudo-hexagonal.

*Additional.* — Both have a prominent basal cleavage, yielding brittle plates, and both are relatively hard.

**CHLORITE GROUP.**

**468. et seq. CHLORITE.** Hydrous silicates of Al, Fe, and Mg. **Hardness 2 ±.**

**Lustre.** — Dull when massive; slightly pearly on cleavage face.

**Color.** — Dark green to grass green.

**Streak.** — White or greenish.

**Cleavage.** — Perfect basal, often apparently absent due to the fineness of the scales or to alteration.

**Cleavage lamellae** are transparent and flexible but not elastic. **Folia** are very tough.

**Sectile.**

Opaque to transparent.

**Massive material** feels slightly soapy.

**S. G.** — 2.35–3.35.

**B. B.** — Usually whitens and fuses with difficulty on edges to a nearly black glass; sometimes exfoliates.

Occurs coarse to fine scaly, granular, and earthy; in plates or disseminated scales; in monoclinic crystals which are usually pseudo-hexagonal and are sometimes vermicular; spheroidal or in fan-shaped or crested groupings; pseudomorphic, or distributed as a pigment through other minerals or rocks.

*Varieties.*

It is convenient to use the name Chlorite so as to embrace a number of very similar mineral species and to regard the latter as not always easily recognizable varieties, the two most important being:

**468. CLINOCHLORE.**

Apt to occur in large, light green, more or less transparent folia but is also found like Prochlorite, below.

**48A. PROCHLORITE.**

Usually scaly granular and rather dull lustrous masses.

Common Chinochlore with Muscovite (p. 205), and Prochlorite with Serpentine (p. 212).

See Fig. 76.

**480. JEFFERISITE.** A hydrous silicate of Al, Fe, and Mg.  
**Hardness 1.5.**

**Lustre.** — Vitreous to slightly pearly on cleavage face.

**Color.** — Yellowish brown.

**Streak.** — White.

**Cleavage.** — Perfect basal.

**Cleavage lamellae** are flexible but are neither elastic nor very tough.

**Sectile.**

**Translucent to transparent.**

**S. G.** — 2.3.

**B. B.** — **Exfoliates** very remarkably and finally becomes white, opaque, and fuses to a gray mass.

**Occurs usually in broad plates.**

**Compare with Biotite (p. 209) and Phlogopite (p. 210).**

**CHLORITE GROUP.**

*Members.* — Chlorite, Jefferisite.

*Composition.* — Hydrous silicates of aluminum, iron and magnesium, principally.

*Crystallization.* — Probably monoclinic; sometimes pseudo-hexagonal.

*Additional.* — Both are very soft and have a perfect basal cleavage, the cleavage lamellae being flexible but non-elastic.



**FIG. 76. — Clinocllore, New York.**

## SERPENTINE-TALC DIVISION.

**481. SERPENTINE.**  $H_2 \left\{ \begin{smallmatrix} Mg \\ Fe \end{smallmatrix} \right\}_2 Si_2O_6 + H_2O$ . Hardness  $4 \pm$

Lustre. — **Wax-like**, greasy or earthy, usually feeble; also silky.

Color. — **Light to dark green**, yellow, brownish red, nearly white, and variegated.

Streak. — White.

**Conchoidal fracture** common when massive.

Tough.

Translucent to opaque.

Feels smooth and sometimes slightly greasy.

S. G. — 2.5–2.65.

B. B. — Fuses only in thin fibres and then with difficulty.

Occurs usually **compact massive or coarse to fine fibrous, like Asbestos** (p. 154), these two habits being often banded; more rarely foliated or as pseudomorphs.

The compact material is microscopically granular or fibrous and felted, and the fibres of the fibrous variety are often easily separable and are usually flexible.

*Varieties.***PRECIOUS or NOBLE SERPENTINE.**

Massive, green material which is translucent even in thick pieces.

**CHRYSOTILE.**

(*Asbestos.*)

The fibrous habit.

**VERD ANTIQUE or OPHICALCITE.**

A mixture of compact Serpentine and Calcite (p. 109), either granular or irregularly aggregated.

Compare the compact material with Cryptocrystalline Quartz (p. 69), Datolite (p. 184), Garnierite (p. 221), and Chrysocolla (p. 228).

Compare Chrysotile with Asbestus (p. 154) and Crocidolite (p. 156).

Serpentine takes a high polish and is much used as an ornamental stone, particularly the Verd Antique.

Chrysotile makes a very fine quality of commercial asbestos.



483. **GARNIERITE.**  $\text{H}_2 \left\{ \begin{smallmatrix} \text{Ni} \\ \text{Mg} \end{smallmatrix} \right\} \text{SiO}_4 + \text{H}_2\text{O}.$   
 (*Genthite, Noumeite.*) Hardness 2-4.

Lustre. — **Varnish-like to dull.**

Color. — **Apple-green.**

Streak. — **Greenish white.**

Brittle. **Conchoidal to uneven fracture.**

Opaque to translucent.

Only rarely adheres to the tongue.

S. G. — 2.41.

B. B. — **Decrepitates but does not fuse.**

Occurs in earthy or loosely compact amorphous masses or crusts which often show a stalactitic or hemispherical surface and have a nodular structure.

Compare with Serpentine (p. 219) and Chrysocolla (p. 228).

The chief source of Nickel but it is said that the supply is greater than the demand.

484. **TALC.**  $\text{H}_2\text{Mg}_3\text{Si}_4\text{O}_{12}$ .

**Hardness 1-1½.**

(*Talcum.*)

**Lustre.** — Wax-like to pearly on cleavage face.

**Color.** — White, light green, greenish gray, dark green, brown, red, silvery white.

**Streak.** — White or greenish.

**Cleavage.** — Perfect basal.

**Thin plates are flexible but not elastic.**

**Sectile.**

**Transparent to translucent.**

**Feels greasy or soapy.**

**S. G.** — 2.7-2.8.

**B. B.** — Whitens and splits but is practically infusible.

Occurs usually **foliated massive**; also **coarse to fine granular** or compact; sometimes fibrous (pseudomorphous). Crystals (indistinctly orthorhombic or monoclinic) are almost unknown.

#### *Varieties.*

### **STEATITE or SOAPSTONE.**

Coarse to fine granular masses which may be as hard as 2.5 due to admixture of impurities.

### **FRENCH CHALK.**

Milk-white, granular or cryptocrystalline material which is soft enough to mark on cloth.

Compare the foliated material with Brucite (p. 107), Muscovite (p. 207), and Gypsum (p. 264).

Compare Soapstone with Chlorite (p. 215), Serpentine (p. 219), Kaolinite (p. 225), and Pyrophyllite (p. 226).

Can be sawn into slabs and used to line furnaces, hearths, etc., or carved into images and trinkets. Is used as chalk for marking on black-boards or cloth and to remove grease-spots from the latter. Also employed to adulterate sugar, flour, and paint and in the manufacture of porcelain, polishing powder (for Verd Antique, Alabaster, and glass), lubricants, gas-jets, tinted plasters, paper, soap, leather dressing, "Talcum Powder," slate-pencils, etc.

**485. SEPIOLITE.**  $H_4Mg_3Si_2O_{10}$ .**Hardness 2-2.5.***(Meerschaum.)***Lustre. — Dull.****Color. — White**, grayish, yellowish or reddish; rarely bluish green.**Streak. — White.****Opaque.****Feels very smooth.****S. G. — 1-2.****B. B. —** Practically infusible but may split, blacken and give a burnt odor, then turn white.Occurs in **tough, earthy masses** which are light enough to float on water when dry; also, rarely, fibrous.

Compare with Mountain Cork (p. 154) and Kaolinite (p. 225).

Used in making fine tobacco pipes and in some places as a building stone and as a substitute for soap.

## KAOLIN DIVISION.

**492. KAOLINITE.**  $H_4Al_2Si_2O_9$ . **Hardness 2-2.5.**  
(*Kaolin, Porcelain- or China-Clay.*)

**Lustre.** — Dull to pearly.

**Color.** — **White, gray, yellowish, brownish, bluish, reddish.**

**Streak.** — Same as the color.

**Conchoidal to uneven fracture when massive.**

**Opaque to translucent.**

**When moistened, has a strong, earthy odor.**

**Often smooth or greasy to the touch.**

**Commonly plastic.**

**S. G.** — 2.61.

**B. B.** — Infusible. **Yields a skeleton of silica in the salt of phosphorus bead.**

Occurs usually in **compact, clay-like, or loose, mealy masses** which are often made up of microscopic pseudo-hexagonal, monoclinic crystals or scales.

Is the principal constituent of clays.

Compare with Bauxite (p. 105).

It is the chief constituent of china, porcelain, stoneware, fire-bricks, fancy tiles, etc.

**497. PYROPHYLLITE.**  $\text{HAlSi}_2\text{O}_6$ . **Hardness 1-2.**

Lustre. — Folia are pearly; massive kinds are dull.

Color. — **White, brown, green, yellowish, gray.**

Streak. — **White.**

Cleavage. — **Perfect basal.**

**Laminae are flexible but not elastic.**

Translucent to opaque.

**Feels greasy or soapy.**

S. G. — 2.8-2.9.

B. B. — Whitens and fuses on the edges with difficulty.  
The radiated variety exfoliates into fan-like forms.

Occurs usually in **radiated lamellar or bladed aggregates** or somewhat fibrous; also granular to compact massive, the latter being sometimes slaty.

*Variety.*

**PENCIL STONE.**

Massive material to which impurities may impart a hardness of 3.

Compare with Talc (p. 222).

The massive variety can only be distinguished from Soapstone (p. 222) by the B. B. test for Mg and Al.

The slaty variety is largely used for the manufacture of slate pencils.

See Fig. 78.

## CONCLUDING DIVISION.

**502. THAUMASITE.**  $\left\{ \begin{array}{l} \text{CaSiO}_3 \\ \text{CaCO}_3 \\ \text{CaSO}_4 \end{array} \right\} + 15 \text{ H}_2\text{O.}$  Hardness 3.5.

Lustre. — Dull.

Color. — White.

Streak. — White.

Brittle. Sub-conchoidal fracture.

Translucent.

S. G. — 1.88.

B. B. — Swells up and colors the flame red but is infusible.  
Effervesces vigorously in cold HCl.

Occurs in compact granular or slightly fibrous masses which are often crumbling and chalk-like on the surface and firm in the interior.

Usually associated with Pectolite (p. 150), Prehnite (p. 189) or some of the Zeolites.

The appearance and associates are distinctive.

**504. CHRYSOCOLLA.**  $\text{CuSiO}_3 + 2\text{H}_2\text{O}$ . **Hardness 2-4.**

Lustre. — Vitreous to dull.

Color. — **Blue to bluish green** or green; sometimes black when impure. **Often spotted with brown** or entirely brown when mixed with Limonite (p. 102).

Streak. — White when pure.

Brittle. **Conchoidal fracture.**

Translucent to opaque.

**Usually adheres strongly to a dry tongue.**

S. G. — 2.2-2.4.

B. B. — Decrepitates, turns black, then brown, and gives Cu flame but is infusible.

Occurs in **smooth, amorphous masses**, opal-like incrustations or seams, earthy, and sometimes botryoidal.

**Often associated with other copper minerals.**

Compare with Opal (p. 76), Malachite (p. 127), Garnierite (p. 221), and Turquoise (p. 247).

A rather unimportant ore of Copper and is sometimes used as a poor imitation of Turquoise (p. 247).



## TITANO-SILICATES.

510. **TITANITE.**  $\text{CaTiSiO}_6$ .

Hardness 5-5.5.

Lustre. — Adamantine to **resinous**.Color. — **Brown** to black, yellow; rarely, green or rose-red.

Streak. — Usually white.

Often has a **perfect parting** due to twinning parallel to one or both faces of a very steep negative pyramid.

Brittle.

Transparent to opaque.

S. G. — 3.4-3.56.

B. B. — Usually becomes yellow and then fuses easily with intumescence to a yellow to black glass.

Occurs usually in tabular or **wedge-shaped monoclinic crystals or platy massive**, rarely lamellar.*Varieties.***LEUCOXENE.**A dull, white, opaque, usually **granular** alteration product.**TITANITE.**

The name is sometimes confined to the brown to black material.

**SPHENE.**

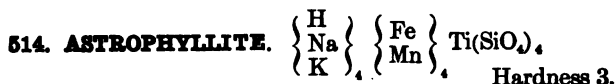
A synonymous name for the species but sometimes confined to the light colored varieties.

**The appearance and manner of occurrence are usually distinctive.**

The transparent, colored varieties are sometimes used as gems.



FIG. 77.



Lustre. — **Bronzy** or pearly.

Color. — **Bronze-yellow** to gold-yellow.

Streak. — White.

Cleavage. — **Perfect brachy-pinacoidal.**

**Cleavage laminae are brittle.**

Translucent to opaque.

S. G. — 3.3–3.4.

B. B. — Swells and fuses easily to a black magnetic enamel.

Occurs usually in **very slender, bladed, micaceous crystals or strips**; rarely in distinct orthorhombic crystals with strongly striated faces.

The blades are usually very confusedly arranged, but are sometimes in stellate groups, and are **usually imbedded in Quartz** (p. 69).

**The appearance and manner of occurrence are distinctive.**

## COLUMBATES AND TANTALATES.

**525. COLUMBITE.**  $\left\{ \begin{array}{c} \text{Fe} \\ \text{Mn} \end{array} \right\} \text{Cb}_2\text{O}_6$  Hardness 6.  
*(Niobite.)*

Lustre. — **Bright sub-metallic** to almost resinous.

Color. — **Black, often iridescent**, rarely brown.

Streak. — **Dark reddish brown** to black.

Cleavage. — **Good macro-pinacoidal and fair brachy-pinacoidal.**

Brittle.

Opaque to translucent.

S. G. — **5.3-7.3.**

B. B. — Unaltered. If fused with KOH and boiled with Sn, a deep blue solution results.

Occurs usually in **short, prismatic orthorhombic crystals or groups of parallel crystals**; also massive.

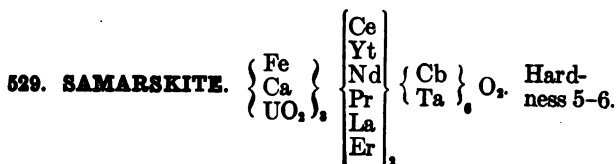
**Usually found in veins in granite.**

*Variety.*

**TANTALITE.**

Like Columbite but the Cb is more or less completely replaced by Ta. The S. G. is higher for Tantalite than for Columbite.

Compare with Wolframite (p. 271).



Lustre. — **High vitreous.**

Color. — **Coal-black.**

Streak. — **Dark reddish brown.**

**No cleavage. Conchoidal fracture.**

**Brittle.**

**Nearly opaque.**

**S. G. — 5.6-5.8.**

**B. B. — Fuses with difficulty on the edges to a black glass. Often yields reactions for Fe.**

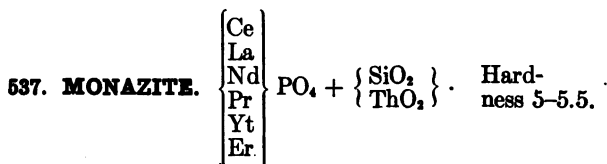
Occurs usually **massive** or as flattened, disseminated grains; rarely in rough orthorhombic crystals.

**The appearance and S. G. are distinctive.**



**FIG. 78. — Pyrophyllite,  
Guilford County, North Carolina.**

## PHOSPHATES, ARSENATES, VANADATES, ETC.



Lustre. — **Resinous.**

Color. — **Yellow, brown, brownish red.**

Streak. — **White.**

Cleavage. — **Good to perfect basal.**

Brittle.

Nearly transparent to opaque.

S. G. — 4.9-5.3.

B. B. — Infusible but turns gray.

Occurs massive; as disseminated grains; as rolled grains with Garnet (p. 166), Magnetite (p. 91), and other heavy sands; rarely in small to large and coarse monoclinic crystals.

The cleavage will distinguish this from all similar minerals. This cleavage can often be seen by cracking some of the grains on an anvil and examining the fragments with a hand-lens.

This is the chief source of the rare earths of which it is composed. Some of these are in great demand for use in manufacturing gas-mantles.

### APATITE GROUP.

**549. APATITE.**  $\left\{ \begin{array}{l} \text{CaF} \\ \text{CaCl} \end{array} \right\} \text{Ca}_5\text{P}_3\text{O}_{12}$  **Hardness 4.5-5.**

Lustre. — Vitreous to resinous or dull.

Color. — **Green**, yellow, brown, gray, red, violet, white.

Streak. — White.

Cleavage. — **Practically none.**

Brittle. Conchoidal to uneven fracture.

Transparent to opaque.

S. G. — 3.2.

**B. B.** — Fuses with difficulty on the edges and gives the blue-green P flame upon the addition of  $\text{H}_2\text{SO}_4$ .

Occurs in pyramidal hemihedral hexagonal crystals, usually showing the basal-pinacoid and a flat pyramid and a prism of the same order, third order forms being very rare; also granular to compact massive and in dull gray or white masses, often globular or reniform, with a more or less evident fibrous or columnar structure.

#### *Varieties.*

### ASPARAGUS STONE.

Pale yellowish green crystals.

### PHOSPHORITE.

Concretionary or stalactitic masses with a fibrous or scaly structure and a hardness of 4.5.

### PHOSPHATE ROCK.

Massive gray, white, brown or black material with a hardness of 2-5.

**OSTEOLITE.**

Compact, earthy, impure, altered, white or gray material with a hardness of 1-2.

**The hardness will distinguish the crystalline material from all similar minerals.**

B. B. tests will often have to be used to distinguish the massive varieties from similar species, particularly the carbonates.

After treatment with  $H_2SO_4$ , to form soluble phosphates, Apatite forms the principal ingredient of most fertilizers. Phosphorus is also obtained from this mineral.



FIG. 79.



**550. PYROMORPHITE.**  $(\text{PbCl}) \text{Pb}_4\text{P}_2\text{O}_{11}$ . **Hard-**  
(*Green Lead Ore.*) **ness 3.5-4.**

**Lustre.** — Resinous.

**Color.** — Green, gray, brown, orange, yellow, white.

**Streak.** — White or yellowish.

**Brittle.** Uneven to sub-conchoidal fracture.

**Translucent to opaque.**

**S. G.** — 5.9-7.1.

**B. B.** — On charcoal, fuses very easily, yielding sublimes of lead oxide and chloride, and the globule on cooling has a polyhedral, crystalline form. In forceps, gives blue-green flame.

Occurs usually in tapering groups of prismatic pyramidal hemihedral hexagonal crystals in parallel positions; also in single crystals which are usually horizontally striated and are often barrel-shaped or show a hollow basal-pinacoid and prism with perhaps a pyramid of the same order, third order forms being very rare; sometimes globular, botryoidal, fibrous or granular.

Compare with *Mimetite* (p. 238).

An ore of Lead.

**551. MIMETITE.**  $(\text{PbCl}) \text{Pb}_4\text{As}_3\text{O}_{13}$ . **Hardness 3.5.**

**Lustre.** — Resinous to adamantine.

**Color.** — Pale yellow to brown; sometimes white or colorless.

**Streak.** — White.

**Brittle.** Uneven fracture.

**Translucent.**

**S. G.** — 7-7.25.

**B. B.** — On charcoal, fuses very easily, yielding sublimates of lead chloride and oxide, and arsenic oxide, finally reducing to metallic Pb.

Occurs in tapering groups of prismatic pyramidal hemihedral hexagonal crystals in parallel position, like Pyromorphite (p. 237) in habit; also in globular groups and in mammillary crusts.

*Variety.*

#### **ENDLICHITE.**

Contains V as well as As.

Compare with Pyromorphite (p. 237).

**552. VANADINITE.**  $(\text{PbCl}) \text{Pb}_4\text{V}_3\text{O}_{12}$ . Hardness 3.

Lustre. — **Resinous** on fracture.

Color. — **Deep red**, reddish brown, yellowish brown or yellow.

Streak. — White to yellowish.

Brittle. Uneven or flat conchoidal fracture.

Translucent to opaque.

S. G. — **6.5-7.25**.

B. B. — Fuses easily on charcoal to a black mass, yielding sublimates of lead chloride and oxide.

Occurs usually in **sharply crystallized, prismatic pyramidal hemihedral hexagonal crystals**, often showing **third order forms and a hollow basal-pinacoid**; also in parallel groupings, rounded forms, and crusts like Pyromorphite (p. 237) and Mimetite (p. 238).

**The crystallization and color are usually distinctive.**

This is the source of the vanadium salts used as a pigment and in several arts and trades.



**FIG. 80.**

**APATITE GROUP.**

*Members.* — Apatite, Pyromorphite, Mimetite, Vanadinite.

*Composition.* — Phosphates etc. of calcium or lead with chlorine and sometimes fluorine.

*Crystallization.* — Pyramidal hemihedral hexagonal.

*Additional.* — Though of differing hardness, they can all be scratched with a knife and none shows cleavage.

MISCELLANEOUS PHOSPHATES,  
ARSENATES, ETC.

**559. AMBLYGONITE.**  $\text{AlPO}_4 \cdot \text{LiF}$ . Hardness 6.

Lustre. — Vitreous to dull.

Color. — White or light tints.

Streak. — White.

Cleavage. — **Good basal** and poor brachy-pinacoidal at an angle of  $75^\circ 30'$ .

Brittle.

Translucent to nearly opaque.

S. G. — 3.05.

B. B. — In forceps, fuses easily with intumescence to an opaque, white bead, giving a red flame. **With  $\text{H}_2\text{SO}_4$ , yields a green P flame.**

Occurs usually in **cleavable masses**; more rarely compact massive or in large, coarse, indistinctly crystallized triclinic crystals.

Compare with Orthoclase (p. 132), Spodumene (p. 148), and Wernerite (p. 175).

A rather rare ore of Lithium.

**561. OLIVENTITE.**  $\text{Cu}_2(\text{OH})\text{AsO}_4$ .  
(*Olive-green Copper Ore.*)

Hardness 3.

Lustre. — Vitreous or adamantine to **silky**.

Color. — **Olive-green** to yellow or brown.

Streak. — Olive-green to brown.

Practically no cleavage. Conchoidal to uneven fracture.

Brittle.

Nearly transparent to opaque.

S. G. — 4.1–4.4.

**B. B.** — On charcoal, fuses easily and with a sudden and sparkling combustion, yielding the sublimate of arsenic oxide, a metallic globule of arsenide of copper, and a bluish green flame.

Occurs in **needle-like orthorhombic crystals forming velvety crusts**; more rarely, in indistinctly fibrous, granular or earthy, nodular masses.

Usually associated with Limonite (p. 104), Malachite (p. 127), Quartz (p. 69), Barite (p. 256), Calcite (p. 109), etc.

The color and manner of occurring are usually distinctive.

An unimportant ore of Copper.

**PHOSPHATES, ARSENATES, VANADATES. 243**

**574. LAZULITE.**  $2\text{AlPO}_4 \cdot (\text{Fe}, \text{Mg}) (\text{OH})_2$ . Hardness 5-6.

**Lustre.** — Vitreous to dull.

**Color.** — Azure-blue.

**Streak.** — White.

**Cleavage.** — None. Uneven fracture.

**Brittle.**

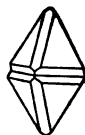
**Opaque.**

**S. G.** — 3.09.

**B. B.** — In the forceps is infusible but whitens, cracks, swells, and falls to pieces, coloring the flame bluish green, particularly when moistened with  $\text{H}_2\text{SO}_4$ .

Occurs in acutely pyramidal monoclinic crystals which are often twinned parallel to the ortho-pinacoid, the twinning plane appearing to be perpendicular to the C axis. Rarely granular to compact massive.

Compare with Turquoise (p. 247).



**FIG. 81. — Twin.**

**597. VIVIANITE.**  $\text{Fe}_3\text{P}_2\text{O}_8 + 8\text{H}_2\text{O}$ .      **Hardness 1.5-2.**  
(*Blue Iron Ore or Earth.*)

**Lustre.** — Vitreous to dull.

**Color.** — **Indigo-blue** or green, deepening on exposure to the light. Colorless before exposure.

**Streak.** — **Indigo-blue.** The colorless or light colored material gives a colorless or bluish streak which soon changes to indigo-blue.

**Cleavage.** — **Perfect pinacoidal.**

**Sectile.** Flexible in thin laminae; otherwise brittle.

**Transparent to opaque.**

**Dichroic.** — Green and blue.

**S. G.** — 2.58-2.68.

**B. B.** — Fuses very easily to a black, magnetic globule, coloring the flame bluish green, particularly after moistening with  $\text{H}_2\text{SO}_4$ .

Occurs usually in radiating, bladed aggregates of monoclinic crystals; also fibrous, incrusting or in earthy masses replacing organic material.

Compare with Azurite (p. 128).



**628. CONIOHALCITE.**  $\left\{ \begin{smallmatrix} \text{Cu} \\ \text{Ca} \end{smallmatrix} \right\}_2 \text{As}_2 \text{O}_7 \cdot \left\{ \begin{smallmatrix} \text{Cu} \\ \text{Ca} \end{smallmatrix} \right\} (\text{OH})_2 + \frac{1}{2} \text{H}_2 \text{O}.$   
 Hardness 4.5.

Lustre. — Dull to waxy.

Color. — **Bright green.**

Streak. — Like color.

Splintery fracture.

Nearly opaque.

S. G. — 4.12.

B. B. — On charcoal, fuses with a sudden and sparkling combustion to a red slag-like mass. In the forceps, fuses, yielding an emerald-green flame.

Occurs in small botryoidal or globular masses which show neither a fibrous or radiating structure, being amorphous; rarely massive.

Compare with Malachite (p. 127).

**639. WAVELLITE.**  $4\text{AlPO}_4 \cdot 2\text{Al}(\text{OH})_3 + 9\text{H}_2\text{O}$ .  
Hardness 3.5-4.

Lustre. — Pearly or brilliant vitreous.

Color. — Green, white, yellow, colorless, blue, gray, brown, black.

Streak. — White.

Cleavage. — Good brachy-pinacoidal.

Brittle.

Translucent.

S. G. — 2.32.

B. B. — Whitens, swells; and splits into fine needle-like particles, but does not fuse.

Occurs in hemispherical or globular aggregates of indistinct orthorhombic crystals with a crystalline surface and radiating structure.

Compare with Prehnite (p. 189) and Thomsonite (p. 203).

**642. TURQUOIS.**  $\text{AlPO}_4 \cdot \text{Al}(\text{OH})_3 + \text{H}_2\text{O} + n\text{Cu}$ .

**Hardness 6.**

**Lustre.** — Dull to feebly waxy.

**Color.** — **Deep blue** to apple-green. Blue material often fades or becomes green.

**Streak.** — White or greenish.

**Cleavage.** — **None.** Conchoidal fracture.

Rather brittle.

Nearly or quite opaque.

S. G. — 2.6–2.83.

**B. B.** — In the forceps, infusible but turns brown and becomes glassy. Yields P flame with  $\text{H}_2\text{SO}_4$  and Cu flame with HCl.

Occurs usually in **amorphous or cryptocrystalline nodules or veins**; also stalactitic, incrusting, as disseminated grains, and in rolled masses.

Compare with Malachite (p. 127), Amazon stone (p. 135), Chrysocolla (p. 228), and Lazulite (p. 243).

It makes a popular and valuable gem, either pure or as "matrix," when of good color and hardness, but is very easily imitated.

**659. TORBERNITE.**  $\text{Cu}(\text{UO}_2)_2\text{P}_2\text{O}_7 + 8\text{H}_2\text{O}$ .

**Hardness 2-2.5.**

(*Uranite, Copper Uranite, Uranium Mica.*)

Lustre. — **Pearly.**

Color. — **Bright yellow-green** to emerald- or grass-green.

Streak. — Lighter than the color.

Cleavage. — **Good basal.**

Brittle.

Transparent to nearly opaque.

S. G. — 3.4-3.6.

B. B. — On charcoal, fuses to a black mass, yielding a green flame.

Occurs usually as **micaceous scales** scattered over the gangue; sometimes in foliated masses or as thin to thick square, or pyramidal, tetragonal crystals.

Compare with Orpiment (p. 19), Autunite (p. 249), and Wulfenite (p. 274).

An ore of Uranium.

**661. AUTUNITE.**  $\text{Ca}(\text{UO}_2)_2\text{P}_2\text{O}_8 + 8\text{H}_2\text{O}$ .

**Hardness 2-2.5.**

**Lustre.** — Pearly.

**Color.** — Bright lemon- or sulphur-yellow.

**Streak.** — Yellowish.

**Cleavage.** — Perfect basal.

**Brittle.**

**Transparent to translucent.**

**S. G.** — 3.05-3.19.

**B. B.** — On charcoal, fuses with intumescence to a black mass.

Occurs like Torbernite (p. 248), but the crystallization is pseudo-tetragonal orthorhombic.

Compare with Orpiment (p. 19), Torbernite (p. 248), and Wulfenite (p. 274).

An ore of Uranium.

**683. SODA NITRE.**  $\text{NaNO}_3$ . **Hardness**  $1\frac{1}{2}$ -2.  
(*Chile Saltpetre, Cubic Nitre.*)

**Lustre.** — Vitreous to dull.

**Color.** — White, colorless, gray, or yellow.

**Streak.** — White.

**Brittle.**

**Transparent to translucent.**

**Tastes salty and cooling.**

**S. G.** — 2.26.

**B. B.** — **Deflagrates and becomes liquid, yielding a yellow flame.**

Occurs as **granular masses** in thick beds or as efflorescent crusts **associated with Halite** (p. 62), **Gypsum** (p. 264), and **other soluble salts**; rarely in rhombohedral crystals that resemble cubes. Crumbles to powder on exposure to the air.

Compare with Kalinite (p. 267) and Alunogen (p. 268).

Used in enormous quantities in the manufacture of nitre, nitric acid, and fertilizers. Often contains sodium iodide as an impurity, and is then the chief source of commercial Iodine.

**BORATES.**

**698. BORACITE.**  $Mg_7Cl_2B_{10}O_{22}$ . Hardness 4.5 or 7.  
(See below.)

Lustre. — Vitreous.

Color. — Colorless or white; sometimes grayish, yellowish or greenish.

Streak. — White.

Brittle. Conchoidal to uneven fracture.

Transparent to opaque.

The massive variety often contains soluble salts which give it an astringent taste.

S. G. — 2.9-3.

B. B. — Fuses easily with intumescence to a white, pearly glass, giving a yellowish green flame.

Occurs in **inclined hemihedral isometric crystals** which are usually isolated and imbedded; also in snow-white earthy masses.

Usually associated with Anhydrite (p. 260), Gypsum (p. 264) or Salt (p. 62).

**The hardness of crystals is 7 and of the massive material 4.5 or much less.**

*Variety.*

**STASSFURTITE.**

The massive material with an earthy or, rarely, a sub-columnar structure.

Compare the crystals with Zunyite (p. 165).

Compare the massive material with Chalk (p. 111) and Borax (p. 253).

**704. COLEMANITE.**  $\text{Ca}_2\text{B}_6\text{O}_{11} + 5 \text{H}_2\text{O}$ . **Hardness 4-4.5.**

Lustre. — Brilliant vitreous to dull.

Color. — White, colorless, yellowish, grayish.

Streak. — White.

Cleavage. — **Perfect clino-pinacoidal.**

Brittle.

Transparent to opaque.

S. G. — 2.42.

B. B. — Decrepitates, exfoliates, and fuses imperfectly, coloring the flame yellowish green.

Occurs usually as **geodes of transparent, colorless, complex monoclinic crystals in the massive material**; also cleavable and chalky or porcelain-like massive.

*Varieties.*

**PRICEITE.**

Loosely adherent, chalky masses.

**PANDERMITE.**

Compact, porcelain-like masses.

Compare the crystallized material with Topaz (p. 179), Heulandite (p. 197), Stilbite (p. 198), and Gypsum (p. 264).

Compare the massive material with Chalk (p. 111) and Cryptocrystalline Quartz (p. 72).



**707. BORAX.**  $\text{Na}_2\text{B}_4\text{O}_7 + 10\text{H}_2\text{O}$ .      **Hardness 2-2.5.**  
(*Tinkal.*)

**Lustre.** — Vitreous or resinous to **dull**.

**Color.** — **White**; sometimes grayish, bluish, greenish.

**Streak.** — **White**.

**Rather brittle.** Conchoidal fracture.

**Transparent** when first formed but becomes earthy and opaque on exposure.

**Has a disagreeable, alkaline taste**, but this is not strong.

**S. G.** — 1.7.

**B. B.** — Swells greatly, finally fusing easily to a transparent glass.

Occurs as a glistening efflorescence on certain soils or as a constituent of the same, and as **well formed monoclinic crystals** — sometimes weighing a pound each — in the mud of borax lakes.

**The taste and appearance are usually distinctive.**

**Is used in great quantities in many arts and trades.**

## URANATES.

**711. URANINITE.** See below.

Hardness 5.5.

(*Pitchblende.*)

Lustre. — **Pitch-like**, sub-metallic, dull.

Color. — Nearly black; sometimes grayish, greenish or brownish.

Streak. — **Olive-green**, gray, dark brown.

Brittle. Conchoidal to uneven fracture.

Opaque.

S. G. — **6.4-9.7.**

B. B. — **Infusible**, or slightly rounded with great difficulty on the edges.

Gives the bead tests for Uranium.

Occurs botryoidal or granular massive and, rarely, in small isometric crystals.

The composition is very variable and complex but it may be said to be a uranate of uranyl ( $\text{UO}_2$ ) and lead, usually with thorium or zirconium and with the metals of the lanthanum and yttrium groups often present; also nitrogen, calcium, water, and radium are always present in small quantities; also Iron as an impurity.

Compare with Samarskite (p. 232).

This mineral is the chief source of the uranium compounds used to color glass and porcelain, and is also in demand for radio-active experiments.

## ANHYDROUS SULPHATES, CHROMATES, ETC.

**716. THENARDITE.**  $\text{Na}_2\text{SO}_4$ .

Hardness 2-3.

Lustre. — **Greasy vitreous.**

Color. — White, **grayish**, brownish.

Streak. — White.

Cleavage. — Practically none. Uneven fracture.

Rather brittle.

Translucent to transparent.

**Tastes bitter and salty.**

S. G. — 2.68.

B. B. — On charcoal, fuses easily to a mass which will stain clean silver, giving a deep yellow flame.

Occurs usually in tabular orthorhombic crystals with rough faces and pointed ends, either simple or as crossed twins; sometimes pyramidal in habit, or massive; also as an efflorescence on alkali earth.

**The taste and appearance are distinctive.**

See Fig. 82.

**BARITE GROUP.****719. BARITE.**  $\text{BaSO}_4$ .**Hardness 2.5-3.5.***(Baryta, Heavy Spar, Baria.)***Lustre.** — Vitreous; sometimes pearly on the basal-pinacoid.**Color.** — White, yellow, gray, blue, brown, red.**Streak.** — White.**Cleavage.** — **Perfect basal and fair prismatic**, the angle of the latter being  $101^\circ 38'$ .**Brittle.****Transparent to opaque.****S. G. — 4.3-4.6.****Sometimes fetid when rubbed.****B. B.** — Decrepitates and fuses fairly easily, yielding Ba flame.

Occurs in **well formed orthorhombic crystals** (see below), aggregates of indistinct tabular crystals united parallel to the flat faces, and **cleavable masses of straight or curved lamellae**; also granular, fibrous, earthy, in globular forms, and like banded stalactite.

Found very commonly as part of the gangue of metallic ores, especially those of Lead.

*Crystals.*

Most of these fall under one of the following habits:

1. *Rhombic Tabular.* The basal-pinacoid and prism are the main forms, the flattening being parallel to the former.
2. *Rectangular Tabular.* The basal-pinacoid and macro- and brachy-domes are the main forms, the flattening being parallel to the first.
3. *Prismatic.* The elongation is usually parallel to the B axis with a macro-dome as the most prominent form.

*ANHYDROUS SULPHATES, CHROMATES.* 257

Rarely the elongation is parallel to the C or A axes.

Broken crystals can always be oriented by means of the cleavage.

**The S. G., hardness, cleavage, and non-effervescence in acids are distinctive.**

Some varieties take a fine polish and look like, and are used in place of Marble (p. 110). Considerable amounts are used to give weight to paper and great quantities are consumed in the adulteration of white lead, the adulterated article being in some respects better than the pure lead.

See Figs. 83 and 84.

**720. OELESTITE.**  $\text{SrSO}_4$ .

Hardness 3-3.5.

Lustre. — Vitreous; sometimes pearly on the basal-pinacoid.

Color. — **Light blue**, white, reddish.

Streak. — White.

Cleavage. — **Good basal and poor prismatic**, the angle of the latter being  $104^\circ 20'$ .

Brittle.

Transparent to nearly opaque.

S. G. — **3.95-3.97**.

B. B. — Usually decrepitates and fuses fairly easily to a white pearl, yielding Sr flame.

Occurs in **orthorhombic crystals with the habits of Barite** (p. 256); also cleavable massive, granular, fibrous, and radiated; sometimes globular.

**Often associated with Sulphur** (p. 3); also in beds of Limestone (p. 111), Gypsum (p. 264) or Salt (p. 62).

Compare with Barite (p. 256).

Is a source of the strontium nitrate used as "red fire" in fireworks.

**ANHYDROUS SULPHATES, CHROMATES. 259**

**721. ANGLESITE.**  $\text{PbSO}_4$ . Hardness 2.75-3.  
(*Lead Vitriol.*)

Lustre. — **High adamantine** to vitreous when in crystals;  
**resinous** to dull when massive.

Color. — White to colorless; also gray, yellow, and light  
green or blue.

Streak. — White.

Cleavage. — **Very poor** basal and prismatic; **usually not  
apparent.**

Very brittle.

Transparent to opaque.

S. G. — **6.12-6.39.**

B. B. — On charcoal, decrepitates and fuses very easily  
to a globule which is milk-white on cooling. In  
R. F. is reduced with effervescence to metallic  
Lead.

Occurs in more or less distinct orthorhombic **crystals in  
cavities in Galenite** (p. 27), being formed by alteration of  
that mineral; commonly in **concentric layers around, or  
pseudomorphous after Galenite**, frequently showing its  
rectangular cleavage by bands of color along the same;  
sometimes stalactitic or in nodular forms.

Compare with Cerussite (p. 124), Barite (p. 256), and  
Celestite (p. 258).

An ore of Lead and frequently carries Silver.

**722. ANHYDRITE.**  $\text{CaSO}_4$ .

Hardness 3-3.5.

Lustre. — Vitreous or pearly.

Color. — **Gray, blue**, white, brown, reddish.

Streak. — White.

Cleavage. — **Perfect to good, parallel to basal-, brachy-, and macro-pinacoids — pseudo-cubic.** Not apparent on most massive varieties.

Brittle.

Translucent to opaque.

S. G. — 2.95.

B. B. — Fuses fairly easily to a white enamel, yielding Ca flame.

Occurs cleavable massive, yielding rectangular fragments, and **coarse to fine granular — marble-like**; also fibrous, lamellar or columnar; rarely in orthorhombic crystals.

*Variety.***VULPINITE.**

Scaly, granular, siliceous material.

Compare with Halite (p. 62) and Calcite (p. 109).

Vulpinite is cut and polished as an ornamental stone.

Anhydrite absorbs water and swells, so cannot be used for building purposes.



**BARITE GROUP.**

*Members.* — Barite, Celestite, Anglesite, Anhydrite.

*Composition.* — Sulphates.

*Crystallization.* — Orthorhombic.

*Additional.* — All are about 3 in hardness, have some degree of cleavage in three directions, and have non-metallic lustres.



FIG. 82. — Thenardite, Borax Lake, California.



FIG. 83. — Barite, Aspen, Colorado.



**FIG. 84.** — Barite, Cumberland, England.

**725. CROCOITE.**  $\text{PbCrO}_4$ .

Hardness 3-3.5.

Lustre. — Adamantine to vitreous.

Color. — **Bright carnelian-red.**

Streak. — **Orange-yellow.**

Cleavage. — Good prismatic at angle of  $86^\circ 19'$ , but cleavage faces are often rough and deeply striated.

Very brittle.

Translucent.

S. G. — 5.9-6.1.

B. B. — On charcoal, fuses very easily with a sudden and sparkling combustion, reducing to metallic Lead, giving a sublimate of lead oxide and finally yielding a residue of chromium oxide.

Occurs usually in **deeply striated, columnar or prismatic aggregates**; rarely in distinct monoclinic crystals of varied habit but usually prismatic; sometimes granular.

Compare with Realgar (p. 18), Vanadinite (p. 239) and Wulfenite (p. 274).

See Fig. 85.

## HYDROUS SULPHATES.

**746. GYPSUM.**  $\text{CaSO}_4 + 2\text{H}_2\text{O}$ . **Hardness 1.5-2.**

Lustre. — **Pearly, silky**, vitreous, dull.

Color. — **White**, gray, red, yellow, blue. Sometimes brown or black when impure.

Streak. — **White**.

Cleavage. — **Very perfect clino-pinacoidal**, fair ortho-pinacoidal, and fair parallel to the positive unit pyramid. **The last two cleavages usually appear as cracks at an angle of  $114^\circ$  in the polished laminae afforded by the perfect cleavage.**

**Thin cleavage laminae are more or less flexible, depending upon the direction in which they are bent.**

Transparent to opaque.

S. G. — 2.32.

B. B. — **Becomes white and opaque and fuses easily, yielding Ca flame.**

**Occurs in well-formed monoclinic crystals which are sometimes twinned in "swallow-tail" forms, and foliated, compact, granular, fibrous, and cleavable massive.**

*Varieties.*

**SELENITE.**

**Crystals and transparent, cleavable plates or strips.**

**SATIN SPAR.**

**White and delicately fibrous with a silky lustre.**

**ALABASTER.**

White or delicately shaded, finely granular material.

**ROCK-GYPSUM.**

Impure, dull colored, scaly to compact material.

The hardness and cleavage should be sufficient to distinguish Gypsum from all similar minerals.

The pure varieties when calcined and ground form plaster of Paris and the impure material is used in many cements. Satin Spar is used in cheap jewelry and Alabaster is easily carved into beautiful statues, vases, etc. Gypsum is also sometimes powdered and used to improve soils.

See Fig. 86.

**755. CHALCANTHITE.**  $\text{CuSO}_4 + 5\text{H}_2\text{O}$ . **Hardness 3.5.**  
(*Blue Vitriol, Copper Vitriol.*)

Lustre. — Vitreous (alters to dull).

Color. — **Deep blue**, sky-blue, or greenish blue.

Streak. — White.

Brittle. Conchoidal fracture.

Transparent; opaque when altered.

**Tastes nauseating and metallic.**

S. G. — 2.12-2.3.

B. B. — Fuses very easily to metallic Cu, yielding a green flame. Dissolves easily in water to a blue solution. If a drop of this solution be placed upon clean Fe, metallic Cu will deposit thereon.

Occurs usually as stalactitic or botryoidal crusts, occasionally fibrous, or in tabular triclinic crystals; rarely massive. It is an oxidation product of Chalcopyrite and other copper sulphides, with which it is usually associated.

Compare with Azurite (p. 128), Lazurite (p. 164), and Vivianite (p. 244).

Too rare to form an ore of Cu, but this metal may often be precipitated from mine waters carrying the Chalcantnite in solution.

**764. KALINITE.**  $K_2SO_4 \cdot Al_2(SO_4)_3 + 24H_2O$ .  
(Potash Alum, Native Alum.) **Hardness 2-2.5.**

Lustre. — Vitreous to dull.

Color. — White.

Streak. — White.

Brittle.

Transparent to translucent.

**Tastes like alum.**

S. G. — 1.75.

**B. B. — Liquefies and then swells to a white, spongy, soft, infusible mass, yielding a violet flame.**

Occurs as a **white efflorescence**, either fibrous or as mealy to compact crusts, **on clays** or other substances containing Kaolin (p. 225).

Compare with Soda Nitre (p. 250) and Alunogen (p. 268).

**775. ALUNOGEN.**  $\text{Al}_2(\text{SO}_4)_3 + 18\text{H}_2\text{O}$ . **Hardness**  $1\frac{1}{2}$ -2.

**Lustre.** — Vitreous or **silky**.

**Color.** — White, yellowish, or reddish.

**Streak.** — White.

**Brittle.**

**Translucent.**

**Tastes like Alum.**

**S. G.** — 1.6-1.8.

**B. B.** — **Liquefies and then forms an infusible mass.**

Occurs in **delicate fibrous, often silky, crusts** of slender monoclinic crystals; rarely massive. **Forms on clays** or other substances containing Kaolin (p. 225), as a result of the action of decomposing sulphides.

Compare with Soda Nitre (p. 250) and Kalinite (p. 267).



**800. ALUNITE.**  $K_2O \cdot 3Al_2O_3 \cdot 4SO_3 \cdot 6H_2O$ . Hardness 3.5–4.  
(*Alum Stone.*)

Lustre. — **Dull** when massive; vitreous when crystalline.

Color. — White with a very **faint flesh tint**, sometimes grayish.

Streak. — White.

Cleavage. — Practically none. **Conchoidal fracture when massive**, uneven when crystalline.

Transparent to nearly opaque.

S. G. — 2.58–2.75.

B. B. — Decrepitates, but is infusible.

Occurs usually **porous granular to compact crypto-crystalline**; the latter being often intermixed with siliceous material; also in nearly cubical rhombohedral crystals or druses of the same in the massive material; sometimes fibrous.

**Cracks and cavities in the massive material are usually coated with Limonite** (p. 104).

Compare with Chert (p. 73) and Magnesite (p. 114).

By calcination, soluble sulphates are formed. These, when evaporated, yield Roman alum which is highly valued by dyers, because, although colored red by iron oxide, it contains no chemically combined iron.

Alunite rock is sometimes used for millstones.



FIG. 85.—Crocoite. Dundas, Tasmania.



FIG. 86.—Gypsum, Mahoning County, Ohio.

## TUNGSTATES AND MOLYBDATES.

**812. WOLFRAMITE.**  $(\text{Fe}, \text{Mn})\text{WO}_4$ . Hardness 5-5.5.  
(*Tungsten.*)

Lustre. — Sub-metallic.

Color. — **Black** or dark gray.

Streak. — Dark brown to black.

Cleavage. — **Perfect clino-pinacoidal.**

Brittle.

Opaque.

S. G. — 7.2-7.5.

B. B. — Fuses easily to a crystalline, magnetic globule.

Occurs in coarsely columnar or bladed aggregates with the cleavage prominent; also frequently in pseudo-orthorhombic, monoclinic crystals which are usually bladed and vertically striated; sometimes coarse to fine granular. Often associated with tin ores.

*Variety.*

### **FERBERITE.**

Contains little or no Mn.

Compare the cleavable material with Huebnerite (p. 272) and Columbite (p. 231).

Compare the granular material with granular Magnetite (p. 91).

Wolframite is used in large quantities in the manufacture of "tungsten steel" and various tungsten salts.

813. **HUEBNERITE.**  $\text{MnWO}_4$ . Hardness 5-5.5.

(*Tungsten.*)

Lustre. — Submetallic or **bronze-like to resinous.**

Color. — **Brown or reddish brown.** Sometimes black.

**Thin fragments are often red by transmitted light.**

Streak. — Brown.

Cleavage. — **Perfect clino-pinacoidal.**

Brittle.

Translucent to opaque.

S. G. — **7.2-7.5.**

B. B. — Fuses with difficulty to a dark globule.

Occurs in **radiating, bladed aggregates with a rough parting along the broad faces**, readily yielding plates in this direction, **this parting being more prominent than the cleavage.** Pseudo-orthorhombic monoclinic crystals rare.

**Often forms veins in Quartz** (p. 69).

Compare with Astrophyllite (p. 230) and Wolframite (p. 271).

Used in large quantities in the manufacture of "tungsten steel" and various tungsten salts.

See Fig. 88.

**SCHEELITE GROUP.**

**814. SCHEELITE.**  $\text{CaWO}_4$ . Hardness 4.5–5.  
(*Tungsten.*)

Lustre. — Vitreous to **adamantine**.

Color. — Pale yellow, brown or gray; sometimes white, green, reddish or orange.

Streak. — White.

Practically no cleavage. Uneven fracture.

Brittle.

Translucent to transparent.

S. G. — 5.9–6.1.

B. B. — Fuses with great difficulty on thin edges. With salt of phosphorous forms a glass which is colorless in the oxidizing, and blue in the reducing flame, if Fe be absent.

Occurs in **well formed pyramidal hemihedral tetragonal crystals** — either individuals or in drusy crusts — usually pyramidal in habit but sometimes tabular parallel to the basal-pinacoid; also granular or compact massive.

Compare with Zircon (p. 178).

Used in the manufacture of “tungsten steel” and various tungsten salts.



FIG. 87.

**818. WULFENITE.**  $\text{PbMoO}_4$ .  
(*Yellow Lead Ore.*)

Hardness 2.75–3.

Lustre. — **Resinous** to adamantine.

Color. — **Bright red to orange**; sometimes brown, grayish white or nearly colorless; rarely green.

Streak. — White.

Cleavage. — Good pyramidal.

**Very fragile and brittle.**

Nearly transparent to nearly opaque.

S. G. — **6.7–7.**

B. B. — On charcoal, fuses very easily, yielding lead oxide sublimate and finally a metallic globule.

Occurs usually in **decidedly tabular pyramidal hemihedral tetragonal crystals**, sometimes very thin and showing the basal-pinacoid and second order pyramid as common, and the third order pyramid as rare, forms. Less frequently the crystals show short, rounded prisms or are pyramidal in habit.

The mineral also occurs granular massive and sometimes the crystallization is so indistinct that the mass appears platy.

Always associated with other lead ores.

Compare with Vanadinite (p. 239) and Crocoite (p. 263).

An unimportant ore of Lead.

See Fig. 89.

**SHEELITE GROUP.**

*Members.* — Scheelite, Wulfenite.

*Composition.* — Tungstates and molybdates.

*Crystallization.* — Pyramidal hemihedral tetragonal.

The group is otherwise not well characterized.



FIG. 88. — Huebnerite, Gladstone, Colorado.



FIG. 89. — Wulfenite, Arizona.

(?) **CARNOTITE.** See below. **Hardness about 1.**

Lustre. — **Dull** to slightly resinous.

Color. — **Canary-yellow.**

Streak. — **Lemon-yellow.**

Brittle. Uneven fracture.

Opaque.

B. B. — In forceps or on charcoal, fuses easily with intumescence to a dull-lustred black globule.

Occurs as a **powder** or in loosely cohering to compact **earthy masses.** Usually intimately **mixed with Quartz sandstone,** and sometimes associated with an olive-green vanadium mica — **ROSCOELITE.** **Does not accompany sulphides** or other easily alterable minerals as it is itself a secondary substance.

Compare with Sulphur (p. 3) and Orpiment (p. 19).

This does not seem to be a homogeneous substance, but appears to be made up of several unidentified minerals. In general, its composition may be said to be a vanadate of uranium and potassium, containing many other bases, including radium.



## HYDROCARBONS.

**OZOCERITE.**  $C_nH_{n+2}$ .**Hardness**  $1 \pm$ *(Native or Mineral Paraffin or Bees' Wax, Ozokerite.)***Lustre.** — **Waxy.****Color.** — **Brown**, yellow-brown, yellow, green, and colorless to white when pure. The brown material is sometimes green by transmitted light.**Streak.** — Light brown to colorless.**Malleable.**

Translucent to nearly opaque.

**Feels greasy**, and has a decided odor.**S. G.** — .85-.90.**B. B.** — **Fuses in a match flame.**

Occurs in structureless or foliated masses which look like, and possess all the properties of, Bees-wax except its stickiness.

It is a natural Paraffin.

**The appearance is distinctive.**

Is used in manufacturing all the products for which Paraffin is in demand.

**AMBER.**  $C_{10}H_{16}O$ .  
(*Succinite.*)

**Hardness 2-2.5.**

Lustre. — **Resinous.**

Color. — **Yellow**, reddish, brownish.

Streak. — **White.**

**Conchoidal fracture.**

Brittle. Can be cut very easily.

Transparent to opaque.

**On being rubbed it becomes negatively electrified and will then pick up small pieces of paper.**

S. G. — 1.05-1.096.

B. B. — Melts very easily and gives off dense white fumes with a peculiar aromatic odor, irritating to the nostrils.

This is a fossil gum or resin which is usually found in loose deposits along coasts, sometimes being washed up on beaches by the waves during storms.

**The appearance, softness, and lightness are characteristic.**

Used principally in jewelry and for the mouth-pieces of fine pipes.

**PETROLEUM.**  $C_nH_{2n+2}+$ . **Thin to thick fluid.**  
(*Oil, Mineral Oil, Naphtha.*)

Lustre. — **Greasy**, watery.

Color. — **Greenish brown to black**; also colorless to dark yellow.

Translucent to transparent.

**Has a disagreeable, "oily" odor.**

S. G. — 0.6-0.9.

**B. B.** — Will burn readily when ignited with a match.

Occurs impregnating sedimentary rocks or collected in cavities in the same, usually beneath gently undulating anticlines. Sometimes seeps out on the surface from inclined strata, forming pools.

#### *Varieties.*

There are many varieties based on composition and fluidity, **Petroleum** varying from a thin, watery liquid, too inflammable to be used in lighting, to very thick, viscid fluids, and passing, by loss of the lighter naphthas through evaporation, by insensible gradations into the paraffins, bitumens or asphalts.

The uses of Petroleum are well known.

**ASPHALTUM.** Mixtures of different hydrocarbons. **Hardness**  $1 \pm$ .  
(*Asphalt; Bitumen; Mineral Pitch, Tar, or Rubber.*)

**Lustre.** — Resinous, pitch-like, dull.

**Color.** — Black, brownish black.

**Streak.** — Brown.

**Conchoidal** to uneven fracture.

**Brittle.** Can be cut very easily.

**Opaque** to transparent.

**Odor** is bituminous.

**S. G.** — 1–1.8.

**B. B.** — Usually melts in a match flame, burning with a bright flame.

Found impregnating, or filling cavities in rocks of all ages, but the most important deposits are in the form of "lakes" or beds on the surface. Such deposits as the last mentioned are probably always connected with rocks containing bituminous material or organic remains.

#### *Varieties.*

There are many varieties based upon the composition, ease of melting, and various physical features.

#### **ELATERITE.**

Mineral rubber.

#### **GRAHAMITE.**

Infusible in a match flame.

Compare with Coal (p. 281).

The uses of Asphaltum in street-paving, roofing, as a wood preservative, etc., are well known.

**COAL.** Oxygenated Hydrocarbons +. Hardness .5-3.

Lustre. — Sub-metallic to dull, also resinous.

Color. — Black to brown, sometimes iridescent.

Streak. — Black to brownish.

Fracture. — Conchoidal to uneven. Rectangular jointing and parting common.

Brittle to tough.

Opaque.

S. G. — 1-1.8.

**B. B. — Burns** more or less freely **without melting.**

Occurs interstratified with sedimentary rocks and beds of iron ore, having been formed by the gradual changes produced in beds of organic materials (chiefly vegetable) through the agency of pressure and more or less heat.

Is usually massive but is sometimes laminated or delicately banded, the different bands differing in color.

#### *Varieties.*

The varieties of coal are based principally on the amount of volatile matter yielded by distillation and on the nature of these compounds. To a less extent the distinctions are based on physical characters.

It is seldom safe to decide the class to which a given specimen of coal belongs without basing the determination on something besides appearance or physical properties.

#### **LIGNITE or BROWN COAL.**

Non-coking, often impure coals containing a large amount of volatile matter. They are of recent origin and the name Lignite is often confined to those varieties which still plainly show the woody structure. Lignite is easily ignited.

The color ranges from **brown** to pitch black and they

are sometimes so compact and hard as to closely resemble Bituminous Coal or even Anthracite, but are usually comparatively soft. Lustre often resinous.

### **JET.**

**Hard, black Lignite with a high lustre which takes a fine polish and is used in jewelry.**

### **BITUMINOUS COAL.**

Coking or non-coking coals with a very large amount (20%–40%) of volatile matter.

The color is **black**, the texture firm and compact and the lustre usually **bright or pitchy**.

Usually **harder than Lignite and softer than Anthracite**.

Easily ignited and burns with a **sooty, yellow flame**.

### **CANNEL or PARROT COAL.**

**Very compact and even in texture with little lustre and a broad conchoidal fracture.**

This is a variety of Bituminous Coal and may be either coking or non-coking.

### **ANTHRACITE.**

**Hard, compact coal with a high, often sub-metallic lustre.** Usually contains less than 5% volatile matter.

**Ignited with difficulty and burns with a blue flame.**

### **MINERAL COKE.**

Resembles artificial coke but is apt to contain bituminous material and be more compact. It is usually plainly formed by metamorphism of coals in contact with igneous intrusions.

### **MINERAL CHARCOAL.**

A fibrous or powdery substance often occurring between layers of coal. It is soft and soils the fingers.

**COMMERCIALLY IMPORTANT ORES.**

In the following table, the figures after each name of an ore indicate the percentage of the element specified which the pure mineral contains. When this is variable or is merely mechanically included, an interrogation mark takes the place of the above-mentioned figure:

Important ores are in **heavy face type**, less common species are in lighter type, and minerals which are only occasionally mined and treated for the element specified are in *italics*.

Each group is arranged in the order of decreasing importance.

**ALUMINUM.**

**Bauxite** (39.2), **Cryolite** (12.8).

**ANTIMONY.**

**Stibnite** (71.8).

**ARSENIC.**

**Arsenopyrite** (46), **Smaltite** (71.8), **Cobaltite** (45.2), **Niccolite** (?), **Enargite** (19.1).

**BARIUM.**

**Witherite** (65).

**BISMUTH.**

**Bismuthinite** (40.6).

**CHROMIUM.**

**Chromite** (46.2).

**COBALT.**

**Smaltite** (?), **Cobaltite** (35.5), **Arsenopyrite** (?).

**COPPER.**

**Native Copper** (95), **Chalcopyrite** (34.5), **Bornite** (55.5), **Cuprite** (88.8), **Malachite** (57.5), **Chalcocite** (79.8), **Enargite** (48.3), **Tetrahedrite** (?), **Azurite** (55.4), **Covellite** (66.4), **Chrysocolla** (45.2), **Atacamite** (62.4), **Tenorite** (79.9).

**GOLD.**

**Native Gold** (99.8), **Pyrite** (?), **Sylvanite** (24.5), **Calaverite** (39.5), **Chalcopyrite** (?), **Hessite** (?), **Pet-zite** (25.5), **Galenite** (?), **Arsenopyrite** (?), **Stibnite** (?).

**IRON.**

**Hematite** (70), **Limonite** (59.8), **Magnetite** (72.4), **Siderite** (48.4), **Goethite** (62.9), **Pyrite** (46.7).

**LEAD.**

**Galenite** (86.6), **Cerussite** (77.7), **Anglesite** (73.6), **Pyromorphite** (76.4), **Mimetite** (69.7), **Vanadinite** (73.2), **Wulfenite** (56.5), **Tetrahedrite** (?).

**LITHIUM.**

**Amblygonite** (4.7), **Spodumene** (3.7).

**MAGNESIUM.**

**Magnesite** (28.6).

**MANGANESE.**

**Pyrolusite** (63.2), **Psilomelane** (?), **Manganite** (62.4).

**MERCURY.**

**Cinnabar** (86.2), *Native Mercury* (99).

**MOLYBDENUM.**

**Molybdenite** (60).

**NICKEL.**

**Garnierite** (?), **Pyrrhotite** (?), **Millerite** (64.4), **Niccolite** (43.9), **Chalcopyrite** (?), **Arsenopyrite** (?).

**PLATINUM.**

**Native Platinum** (86.5).



**SILVER.**

**Galenite** (?), **Cerargyrite** (75.3), **Pyrargyrite** (59.9), **Proustite** (65.4), **Argentite** (87.1), **Tetrahedrite** (?), **Native Silver** (95), **Native Gold** (?). **Native Copper** (?), **Hessite** (63), **Petzite** (43), **Stephanite** (68.5), **Pyrite** (?), **Chalcopyrite** (?), **Jamesonite** (?), **Stibnite** (?), **Cerussite** (?), **Polybasite** (75.6).

**STRONTIUM.**

**Strontianite** (56.8), **Celestite** (45.7).

**SULPHUR.**

**Pyrite** (53.3), **Native Sulphur** (100), **Pyrrhotite** (?).

**THORIUM.**

**Monazite** (?).

**TIN.**

**Cassiterite** (78.6).

**TITANIUM.**

**Rutile** (59.9).

**TUNGSTEN.**

**Wolframite** (60.7), **Huebnerite** (60.7), **Scheelite** (63.9).

**URANIUM.**

**Uraninite** (?), **Carnotite** (?), **Autunite** (51.9), **Torbernite** (50.8), **Samarskite** (?).

**VANADIUM.**

**Vanadinite** (10.8), **Carnotite** (?).

**ZINC.**

**Sphalerite** (67), **Smithsonite** (52), **Calamine** (54.1), **Zincite** (80.8), **Franklinite** (?), **Willemite** (58.4).

Note: In the foregoing table, **Marcasite** is included under **Pyrite**, and **Tennantite** under **Tetrahedrite**.

**RETAIL PRICES OF GOOD TO VERY FINE CUT GEMS**

Note: The value of gems depends upon five factors, *i.e.*, (1) the color, (2) freedom from flaws and inclusions, (3) the hardness, (4) the coefficient of refraction, and (5) the rarity.

Unless the color is unusually good and the material is uncommonly free from flaws, it will seldom pay to try to market uncut gem materials if listed at less than \$2.00 per carat.

Good gems are occasionally quoted at lower figures than are here given and very large gems of the cheaper varieties often cost much less per carat than do smaller stones, but these figures are probably fair average values. Large gems of the more expensive varieties usually cost much more per carat than do the small ones.

The price charged by Lapidaries for facetting a single stone will vary from about \$1.00 to \$3.50 per carat according to the hardness of the mineral and the difficulties due to cleavage, etc., which are apt to be encountered. The cutting of Diamonds costs much more than this. When a great many stones of the minerals about 7 in hardness are cut at one time, a figure of as low as \$0.20 apiece can sometimes be obtained if the stones are not over a carat in size. The cost of cutting cabochon (with a rounded surface) is considerably less than facetting.

A carat is a weight of about 3.2 Troy grains or 1/2187 of a pound Avoirdupois.

Uncut gem material is sold by the pound, or by the specimen if very valuable.

Most of the gems listed are described in this book.

	Retail price per carat.
Alexandrite . . . . .	\$20.00 to \$150.00
Amazon Stone . . . . .	.50
Amethyst (Quartz) . . . . .	.50 to 5.00
Amethyst, oriental . . . . .	5.00 to 30.00
Aquamarine . . . . .	4.00 to 20.00
Azurite . . . . .	.75 to 2.00
Beryl (Aquamarine). (See Aquamarine.)	
Beryl, pink . . . . .	5.00 to 10.00

# RETAIL PRICES OF CUT GEMS. 287

	Retail price per carat.
Benitoite . . . . .	\$10.00 to \$20.00
Beryl (Emerald). (See Emerald.)	
Bloodstone. (See Heliotrope.)	
Californite . . . . .	.50 to 2.00
Chlorastrolite . . . . .	.50 to 5.00
Chrysoberyl . . . . .	10.00 to 15.00
Chrysoberyl, var. Cat's Eye . . . . .	5.00 to 50.00
Chrysocolla, siliceous . . . . .	1.00 to 2.50
Chrysoprase . . . . .	.50 to 2.00
Citrine . . . . .	1.00 to 5.00
Cyanite . . . . .	
Cymophane . . . . .	20.00
Diamond, white . . . . .	175.00 to 300.00
Diamond, brown . . . . .	150.00 to 500.00
Diamond, canary yellow . . . . .	500.00
Diamond, blue . . . . .	250.00 to 500.00
Diopside . . . . .	3.00 to 5.00
Emerald (Beryl) . . . . .	25.00 to 200.00
Emerald, oriental . . . . .	500.00 to 1000.00
Epidote . . . . .	2.00 to 10.00
Fire Opal. (See Opal.)	
Garnet . . . . .	.50 to 12.00
Heliotrope . . . . .	.50
Hiddenite . . . . .	15.00 to 75.00
Hyacinth . . . . .	5.00 to 15.00
Jacinth or Hyacinth. (See Hyacinth.)	
Jade . . . . .	.50 to 3.00
Jargon . . . . .	10.00 to 20.00
Kunzite . . . . .	12.00 to 18.00
Lapis Lazuli . . . . .	.50 to 1.00
Malachite . . . . .	.75 to 2.00
Malachite and Azurite . . . . .	.75 to 2.00
Matrix Turquoise, variety. (See Turquoise.)	
Mexican Opal, variety. (See Opal, precious.)	
Montana Sapphire, variety. (See Sapphire.)	
Moonstone . . . . .	.50 to 1.50
Moss Agate . . . . .	.50
Opal, fire . . . . .	.25
Opal, precious . . . . .	2.00 to 25.00
Oriental Amethyst, variety. (See Amethyst.)	

Retail price per carat.

Oriental Emerald, variety. (See Emerald.)	
Oriental Ruby, variety. (See Ruby.)	
Oriental Sapphire, variety. (See Sapphire.)	
Oriental Topaz, variety. (See Topaz.)	
Peridot . . . . .	\$4.00 to \$15.00
Precious Opal, variety. (See Opal.)	
Quartz, Rose . . . . .	2.00
Quartz, Smoky . . . . .	1.50
Rose Quartz, variety. (See Quartz.)	
Ruby, Arizona, variety of Garnet . . . . .	1.50 to 12.00
Ruby, oriental . . . . .	25.00 to 1000.00
Ruby Spinel, variety. (See Spinel.)	
Sapphire, oriental . . . . .	25.00 to 140.00
Sapphire, Montana, blue . . . . .	3.50 to 40.00
Sapphire, Montana, pink . . . . .	5.00 to 30.00
Smoky Quartz, variety. (See Quartz.)	
Spinel Ruby . . . . .	8.00 to 20.00
Sunstone . . . . .	.50 to 2.00
Thomsonite . . . . .	.50
Titanite . . . . .	7.50 to 15.00
Topaz, blue . . . . .	3.00 to 10.00
Topaz, golden . . . . .	2.00 to 8.00
Topaz, pink . . . . .	4.00 to 8.00
Topaz, oriental . . . . .	5.00 to 30.00
Topaz, white . . . . .	2.00 to 8.00
Tourmaline, pink . . . . .	4.00 to 15.00
Tourmaline, green or brown . . . . .	5.00 to 12.00
Turquoise . . . . .	2.00 to 12.00
Turquoise, matrix . . . . .	.50
Varicite . . . . .	1.50

**VALUES OF METALS AND MINERALS.**

All these figures fluctuate, but they will often at least give a prospector some idea as to whether or not a deposit is worth "locating."

**METALS.**

Aluminum (99%), per pound . . . . .	\$ .20 to \$ .35
Antimony, per pound . . . . .	.08 to .10
Bismuth, per pound . . . . .	2.10 to 2.15
Cadmium, per pound . . . . .	.70 to .75
Copper, per pound . . . . .	.13
Gold, per ounce . . . . .	20.00
Lead, per pound . . . . .	.04 to .05
Magnesium, per pound . . . . .	1.50
Mercury, per flask of 75 pounds . . . .	35.00 to 50.00
Nickel, per pound . . . . .	.50 to .55
Platinum, per ounce . . . . .	45.00
Silver, per ounce . . . . .	.53
Tin, per pound . . . . .	.35 to .45
Zinc, per pound . . . . .	.07 to .08

**MINERALS.**

Asphaltum, per ton . . . . .	\$22.50 to \$150.00
Barite (ground and floated), per ton . .	12.00 to 22.50
Borax, per pound . . . . .	.04
Bort, per carat . . . . .	50.00 to 75.00
Calcite (ground), per ton . . . . .	9.50 to 10.00
Chalk, per ton . . . . .	3.00
Columbite (40% tantalic acid), per pound .	.20
Corundum, per pound . . . . .	.07 to .10
Cryolite, per pound . . . . .	.07
Emery (ground), per pound . . . . .	.02 to .05
Feldspar (ground), per ton . . . . .	6.00 to 14.00
Fluorite (lump), per ton . . . . .	8.00 to 10.00
Fluorite (ground), per ton . . . . .	12.00 to 14.00
Garnet, per ton . . . . .	25.00 to 30.00
Garnierite (50%), per ton . . . . .	14.00 to 16.00

Graphite, per pound . . . . .	\$ .02 to \$ .12
Gypsum (ground), per ton . . . . .	4.00 to 7.00
Infusorial Earth, per pound . . . . .	.02 to .03
Iron Oxides, per ton . . . . .	3.50 to 4.50
Kaolin, per ton . . . . .	8.00 to 18.00
Magnesite, per ton . . . . .	7.50 to 8.50
Molybdenite (95%), per ton . . . . .	500.00 to 600.00
Monazite Sand (95% sand with 5% thor- ium oxide), per pound . . . . .	.08 to .10
Muscovite (ground), per ton . . . . .	12.00 to 20.00
Muscovite (scrap), per ton . . . . .	15.00 to 75.00
Ozocerite, per pound . . . . .	.12 to .16
Phosphate Rock, per ton . . . . .	3.50 to 6.50
Pyrite (non-arsenical), per unit of sulphur . . . . .	.10 to .13
Pyrite (arsenical), per unit of sulphur . . . . .	.10
Pyrolusite (80%-85% $\text{MnO}_2$ ), per ton . . . . .	15.00 to 30.00
Quartz (lump), per ton . . . . .	5.00 to 5.50
Quartz (ground), per ton . . . . .	7.00 to 15.00
Rutile (90%), per ton . . . . .	120.00 to 160.00
Salt (lump), per ton . . . . .	4.00 to 4.50
Sulphur, per ton . . . . .	22.00
Talc, per ton . . . . .	15.00 to 25.00
Tungsten (50% $\text{WO}_3$ ), per unit . . . . .	7.50
Witherite (80%-90%), per ton . . . . .	26.00 to 35.00

(NOTE: The above quotations are those prevailing previous to the European war. The high values demanded for metals and minerals during the continuance of this conflict are doubtless in most cases temporary, and are subject to such fluctuations that it was not deemed best to attempt to give them here.)

**GLOSSARY.**

(With examples.)

- Acicular.* Needle-like. (Natrolite.)
- Adamantine Lustre.* The lustre of oiled-glass, exhibited by minerals with a high index of refraction. (Diamond, Cerussite.)
- Aggregates.* Clusters or groups.
- Alkaline Taste.* Like soda. (Natron, Borax.)
- Amorphous.* Without crystalline form or structure, *i.e.*, without a regular arrangement of the molecules. (Opal, Turquoise.)
- Arborescent.* Resembling a tree in appearance. (Native Copper and Silver.)
- Astringent Taste.* Causing the mouth to "pucker." (Some Boracite.)
- Basal Cleavage.* Same as pinacoidal (*q. v.*), but is parallel to the basal pinacoid, *i.e.*, is usually perpendicular to the direction of elongation. (Topaz, Apophyllite.)
- Bladed.* Decidedly elongated and flattened. (Wollastonite, Cyanite.)
- Botryoidal.* Globular masses so united as to resemble a bunch of grapes. (Chalcedony, Prehnite.)
- Brittle.* The quality which causes a substance to break readily when struck with a hammer. (Sulphur, Pyrite.)
- Capillary.* Hair-like. (Millerite, Mesolite.)
- Chatoyant Lustre.* Changeable, undulating reflections from beneath the surface. (Moonstone, Crocidolite.)
- Cleavage.* The property possessed by many crystalline substances which causes them to break more or less easily and smoothly in definite directions, *i.e.*, parallel to possible crystal faces. (Galenite, Calcite.)
- The cleavage may be very perfect, perfect, good, fair, or poor depending upon the ease with which it can be developed and the smoothness of the resulting faces.
- Cleavage faces may usually be distinguished from crystal faces by the fact that they appear to be covered with thin plates, forming low steps.
- Cleavage is said to be cubical, octahedral, dodecahed-

ral, pyramidal, prismatic, pinacoidal,\*basal, and rhombohedral, q. v.

More than one kind of cleavage is often found on one mineral.

*Columnar.* Column-like forms, usually in nearly parallel position. (Stibnite, Jamesonite.)

*Compact.* Made up of very fine, closely united particles. (Magnesite, Datolite.)

*Conchoidal Fracture.* Smoothly curving like the interior of a shell.

The following three kinds of substances may show a conchoidal fracture:

1. Amorphous substances. (Chrysocolla.)
2. Cryptocrystalline or very fine grained. (Chalcocite.)
3. Individual crystals without cleavage. (Quartz.)

*Concentric.* Showing spherical crusts or layers, one within another. (Arsenic.)

*Contact Twin.* The simplest type of twin (q. v.), in which two portions of a crystal appear to have been united along a common plane after one portion has been revolved  $180^\circ$  relative to the other. The plane of contact (plane of union or the composition face) may or may not be the twinning plane. (Hornblende, Epidote.)

*Cryptocrystalline.* ("Hidden crystalline.") Composed of microscopic crystals or crystalline grains, i.e., very fine grained. (Chalcedony, Datolite.)

*Crystal.* A mineral bounded wholly or partially by natural plane surfaces, called faces.

*Crystalline.* With a regular molecular arrangement. This is manifested in many ways, such as a definite external form—"crystals," the presence of cleavage, or the ability to polarize light. (Orthoclase, Quartz.)

*Cubical Cleavage.* Equally good cleavage in three directions at angles of  $90^\circ$ . (Galenite, Halite.)

*Cyclic Twin.* Composed of parts which appear to have been alternately revolved  $180^\circ$  upon non-parallel twinning planes. The varieties with names are trillings, fourlings, sixlings and eightlings, q. v.

*Decrepitate.* Fly to pieces when heated with a blowpipe. (Jamesonite, Halite.)



- Deflagrate.* To show sudden and sparkling combustion.
- Deliquescent.* Capable of extracting considerable water from the air and thus tending to form a liquid.
- Dendritic.* Fern-like. (Native Copper, Wad.)
- Dichroic.* Exhibiting different colors or tints when looked through in different directions. Only seen in transparent minerals. (Epidote, Vivianite.)
- Dimorphic.* A term applied to a substance which crystallizes in two systems, or in one system with absolutely different unit axial values. ( $\text{FeS}_2$ ,  $\text{CaCO}_3$ .)
- Disseminated.* Scattered rather uniformly through something. (Precious Metals.)
- Dodecahedral Cleavage.* Equally good cleavage in six directions at angles of  $60^\circ$ ,  $90^\circ$  and  $120^\circ$ . (Sphalerite, Sodalite.)
- Druse.* A great many very small crystals crowded closely together. (Calamine, Chabazite.)
- Ductile.* Capable of being drawn into wire. (Copper, Platinum.)
- Dull Lustre.* Without "shine" of any kind. (Chalk, Hydrozincite.)
- Earthy.* Earth-like.
- Efflorescence.* A crust, powder, or crystalline coating formed on the surface by the evaporation of mineralized water. (Borax, Thenardite.)
- Eightling.* A cyclic twin (q. v.) made up of eight portions. (Rutile.)
- Elastic.* The property which causes a portion of a substance to resume its original position after it has been displaced. (Capillary Millerite, Muscovite.)
- Electrified.* When a substance is electrified, it attracts, and picks up, small particles of tissue paper.
- Exfoliate.* To swell or puff out when heated with the blowpipe, due to a separation into leaves or folia. (Stilbite, Jefferisite.)
- Feldspathoid.* A mineral resembling a feldspar in composition but differing in physical characteristics. (Leucite, Sodalite, Nephelite.)

- Fetid.* Having the odor of  $H_2S$ , or bad eggs. (Some Limestone and Barite.)
- Fibrous.* Composed of fine, slender filaments or fibres. (Asbestos, Crocidolite.)
- Filiform.* Wire- or thread-like. (Millerite, Mesolite.)
- Flexible.* Capable of being bent without fracture. (Chlorite, Gypsum.)
- Foliae.* Same as lamellae, q. v.
- Foliated.* Leafy or platy. (Micas, Talc.)
- Fourling.* A cyclic twin (q. v.) made up of four portions. Rare.
- Fracture.* The manner in which a mineral breaks other than along cleavage or parting planes. Fracture is said to be uneven, hackly, splintery or conchoidal, q. v.
- Gangue.* The worthless rock or minerals in which a more valuable or interesting mineral is imbedded or to which it is attached.
- Granular.* Composed of coarse to fine grains. (Pyrrhotite, Emery.)
- Globular.* Globe-like. (Conichalcite, Wavelite.)
- Habit.* The manner of occurrence of a mineral, such as botryoidal, compact-massive, etc.
- Hackly.* Jagged; covered with sharp points. (Native Metals.)
- Hardness.* The power of resisting abrasion or scratching. See Moh's scale of hardness elsewhere.
- Imitative.* Resembling some familiar object or form. See acicular, arborescent, botryoidal, dendritic, lenticular, nodular, oolitic, pisolitic, reniform, reticulated, stalactitic, etc.
- Incrusted.* Covered with a thin layer or crust.
- Incrusting.* Occurring as a thin layer or crust on something else. (Millerite, Marcasite.)
- Interpenetration Twins.* A term applied to two or more crystals in twinned (q. v.) position when they penetrate each other, being not merely united by the adherence of external faces. (Carlsbad twins of Orthoclase, Thenardite.)
- Intumescence.* Boiling when heated with the blowpipe. (Chabazite, Thomsonite.)

*Iridescent.* Showing a play of prismatic colors. (Many sulphides.)

*Isomorphic.* Two minerals of different compositions but the same crystallization. (Argentite, Galenite.)

*Isomorphic Group.* A group of minerals all of which crystallize alike. (Pyrite Group, Calcite Group.)

*Lamellar.* Same as foliated, q. v.

*Lamellae.* Thin plates, leaves, or sheets. (Brucite, Micas.)

*Laminated.* Same as foliated, q. v.

*Laminae.* Same as lamellae, q. v.

*Lenticular.* Lens-shaped. (Some Calcite crystals and many nodules, q. v.)

*Lustre.* The manner in which a substance reflects light. The following different varieties are recognized: adamantine, chatoyant, dull, greasy, metallic, pearly, resinous, silky, stony, q. v.

The intensity of the lustre is indicated by the use of the terms splendid, brilliant, shining, glistening, etc.

The prefix sub is used to indicate an imperfect lustre of the kind specified.

*Magnetic.* Attracted to the magnet. (Magnetite, Pyrrhotite.)

*Malleable.* Capable of being hammered into thin sheets. (Gold, Silver.)

*Mammillary.* Rounded protuberances with the form of flat domes. (Hematite, Aragonite.)

*Massive.* In masses without definite crystalline form. (Thaumasite, Serpentine.)

*Metallic Lustre.* The lustre of a metal. (Galenite, Chalcopyrite.)

*Micaceous.* Composed of small plates or leaves. (Micaceous Hematite, Astrophyllite.)

*Mineral.* A natural occurring, homogeneous, inorganic substance. (Quartz, Gold.)

*Multiple Twin.* Composed of parts which appear to have been alternately revolved  $180^\circ$  upon parallel or non-parallel twinning planes. These are of two kinds, i.e., cyclic twins and oscillatory twins, q. v.

*Nodular.* Completely spherical, ovoid, or disk-shaped; usually imbedded in some other material.

*Nodules.* Spherical, ovoid, disk-shaped, cylindrical, or imitatively shaped forms which are made by the segregation of some foreign substance disseminated in small amounts through some different material. The segregation often takes place around a nucleus of organic matter.

As used in mineralogy, the term is applied to anything with either of the first three above mentioned shapes, regardless of how it was formed.

*Octahedral Cleavage.* Equally good cleavage in four directions at angles of about  $109^{\circ}$  and  $71^{\circ}$ . (Diamond, Fluorite.)

*Oolitic.* Composed of small globules like fish eggs. (Oolitic Hematite, Oolitic Calcite.)

*Opalescence.* A milky or pearly appearance, due to reflection from below the surface. (Opal.)

*Opaque.* Does not transmit light even on thin edges. (All minerals with a metallic lustre, and many others.)

*Oscillatory Twins.* Composed of laminae or parts which appear to have been alternately revolved  $180^{\circ}$  upon parallel twinning planes. (Plagioclases, Calcite.)

*Paramorph.* A crystal that has undergone a change in its physical properties without a corresponding change in composition. (Calcite to Aragonite, Pyroxene to Hornblende.)

*Parting.* A separation other than cleavage in a rather definite direction. This may coincide with some crystallographic direction as in the case of parting due to twinning (Calcite, Titanite, Corundum), or it may be in any direction as when produced by pressure.

Parting can be distinguished from cleavage by the fact that it cannot be induced anywhere on a specimen, but will only occur along lines of weakness.

*Pearly Lustre.* Like mother-of-pearl. (Apophyllite, Muscovite.)

*Penetration Twins.* Same as interpenetration twins, q. v.

*Phenocrystalline.* Evidently crystalline. Not necessarily in distinct crystals but the crystalline structure can be readily proven by the presence of cleavage or peculiar optical characteristics. (Rose Quartz, etc.)

*Pinacoidal Cleavage.* Cleavage in only one direction. (Topaz, Colemanite.)

*Pisolitic.* Composed of globules between the size of "BB" shot and peas. (Pisolitic Calcite.)

*Pleochroic.* Exhibiting several different colors or tints when looked through in different directions. See dichroic.

*Polarize.* A substance is said to polarize light when all the rays that pass through it are forced to vibrate in two planes at right angles to each other. All crystalline substances except those in the isometric system will do this.

*Polysynthetic Twins.* ("Many unions.") Same as oscillatory twins, q. v.

*Primary.* Original. A mineral which crystallized when the rock in which it is embedded was formed is said to be primary.

*Prismatic.* Elongated decidedly in one direction but with sufficiently large dimensions in other directions to prevent it from being called acicular, capillary, or bladed, q. v. (Actinolite, Staurolite.)

*Prismatic Cleavage.* As usually used, this means equally good cleavage in two directions, the angle varying with the system, and being 90° for tetragonal minerals, only. (Enargite, Wernerite.)

In the case of the hexagonal minerals, the corresponding cleavage should be called hexagonal prismatic, and means equally good cleavage in three directions at angles of 60° and 120°.

*Pseudomorph.* A substance occurring with the crystalline form of another, due to the alteration or replacement of the second to or by the first. (Martite, Limonite after Pyrite.)

*Pyramidal.* Resembling a pyramid, i.e., a form bounded by triangular faces which meet in a common point.

*Pyramidal Cleavage.* As usually used, this means equally good cleavage in four directions at varying angles. Rare.

In the case of the hexagonal minerals the corresponding cleavage should be called hexagonal pyramidal, and means equally good cleavage in six directions at varying angles. Rare.

*Reniform.* Kidney-shaped. (Some Hematite and Limonite.)

*Repeated Twins.* Same as multiple twins, q. v.

*Reticulated.* Showing fibres crossed like a net. (Stibnite, Rutile.)

*Resinous Lustre.* Resembling resin, or rosin. (Realgar, Sphalerite.)

*Rhombohedral Cleavage.* Equally good cleavage in three directions at varying angles. (Calcite, Rhodochrosite.)

*Rock.* Any substance not a liquid which forms a considerable portion of the earth's crust. (Limestone, Phosphate Rock.)

*Scaly.* Made up of very small leaves or scales. (Some Kaolin.)

*Secondary.* A mineral whose formation took place after the rock in which it is imbedded was formed is said to be secondary. (Kaolin, Chlorite.)

*Sectile.* Capable of having little slices or shavings cut from it with a knife. (Orpiment, Argentite.)

*Silky Lustre.* With a sheen like silk. (Malachite, Pectolite.)

*Sixling.* A cyclic twin (q. v.) made up of six portions. (Aragonite, Witherite.)

*Spar.* A name given by miners to almost any cleavable mineral with a vitreous lustre. (Fluor-spar, Heavy-spar.)

*Specific Gravity* (S. G.). This equals the quotient obtained by dividing the weight of a substance by the weight of an equal volume of water at 15° C. The result shows how many times heavier or lighter than water the substance tested is.

The average S. G. of the materials of the earth's crust

is about 2.5; anything above this figure is regarded as heavy and anything under this will seem light.

*Splintery Fracture.* Breaking into long slivers or splinters. Rare.

*Stalactitic.* Resembling an icicle. (Calcite, Aragonite.)

*Stellate.* Star-like. (Strontianite and Cerussite twins.)

*Stony Lustre.* The lustre of weathered rocks. (Orthoclase, Spodumene.)

*Streak.* The color of the powdered mineral. It is usually obtained by rubbing the mineral upon a piece of unglazed porcelain, called a streak plate.

If the lustre is metallic, the streak will usually be as dark or darker in color than is the mineral itself. If the lustre is not metallic, the opposite is usually true.

*Striated.* Covered with striations, q. v.

*Striations.* Very distinct, parallel lines which are really a succession of very minute ridges and furrows or very low steps. They may be produced in the following two ways:

1. By the oscillation or alternate appearance of different crystal faces, thus forming a series of low steps. Striations of this character are confined to the surface of crystals. (Pyrite, Garnet.)
2. By oscillatory or repeated twinning. Striations thus produced are to be seen on cleavage, as well as crystal faces. (Plagioclases, Corundum.) Sometimes striation-like lines are produced by cleavage or other causes, but these are disregarded.

*Sulpho Salt.* A compound containing one or more bases combined with Sulphur and a semi-metal, the latter being united in a definite ratio.

*Tabular.* Tablet-shaped. (Barite, Wulfenite.)

*Tarnish.* A very thin coating formed on many minerals by slight changes in composition induced by exposure to the atmosphere. (Arsenic, Bornite.)

*Termination.* The group of faces enclosing the end of an elongated crystal.

*Titano-silicate.* A compound composed of one or more bases united to both titanic and silicic acids.

*Tough.* Not easily broken with a hammer. (Mountain Cork, Sepiolite.)

*Transparent.* Objects can be seen through the substance. (Rock Crystal, Iceland Spar.)

*Translucent.* Objects cannot be seen through the substance but light is transmitted through the same. (Orpiment, Crocoite.)

*Triboluminescence.* The property which causes a mineral to become luminous or emit sparks at any point where lightly scratched with steel. (Some Sphalerite, Smithsonite, and Limestone.)

*Trilling.* A cyclic twin made up of three portions. Rare.

*Twin.* Two or more crystals or portions of one crystal so united that, if alternate crystals or portions could be revolved  $180^\circ$  on so-called twinning planes, one simple untwinned crystal would be formed.

The twinning planes cannot be parallel to symmetry planes and must be parallel to possible crystal faces.

Three classes of twins are recognized, *i.e.*, contact twins, interpenetration twins and multiple twins, q. v.

*Uneven Fracture.* Rough fracture. (Tetrahedrite. Milky Quartz.)

*Vitreous Lustre.* The lustre of glass. (Topaz, Tourmaline.)



TABLE OF ELEMENTS WITH THEIR SYMBOLS  
AND ATOMIC WEIGHTS.

Name.	Sym- bol.	At. Wts.	Name.	Sym- bol.	At. Wts.
Aluminium . . .	Al	27.1	Neodymium . . .	Nd	143.6
Antimony . . .	Sb	120.2	Neon . . . . .	Ne	20.
Argon . . . . .	A	39.9	Nickel . . . . .	Ni	58.7
Arsenic . . . . .	As	75.	Nitrogen . . . .	N	14.04
Barium . . . . .	Ba	137.4	Osmium . . . . .	Os	191.
Beryllium . . . .	Be	9.1	Oxygen . . . . .	O	16.
Bismuth . . . . .	Bi	208.5	Palladium . . . .	Pd	106.5
Boron . . . . .	B	11.	Phosphorus . . .	P	31.
Bromine . . . . .	Br	79.96	Platinum . . . .	Pt	194.8
Cadmium . . . . .	Cd	112.4	Potassium . . . .	K	39.15
Caesium . . . . .	Cs	132.9	Praseodymium . .	Pr	140.5
Calcium . . . . .	Ca	40.1	Radium . . . . .	Ra	225.
Carbon . . . . .	C	12.	Rhodium . . . . .	Rh	103.
Cerium . . . . .	Ce	140.25	Rubidium . . . .	Rb	85.4
Chlorine . . . . .	Cl	35.45	Ruthenium . . . .	Ru	101.7
Chromium . . . . .	Cr	52.1	Samarium . . . . .	Sm	150.
Cobalt . . . . .	Co	59.	Scandium . . . . .	Sc	44.1
Columbium . . . .	Cb	94.	Selenium . . . . .	Se	79.2
Copper . . . . .	Cu	63.6	Silicon . . . . .	Si	28.4
Erbium . . . . .	Er	166.	Silver . . . . .	Ag	107.93
Fluorine . . . . .	F	19.	Sodium . . . . .	Na	23.05
Gadolinium . . . .	Gd	156.	Strontium . . . .	Sr	87.6
Gallium . . . . .	Ga	70.	Sulphur . . . . .	S	32.06
Germanium . . . .	Ge	72.5	Tantalum . . . . .	Ta	183.
Gold . . . . .	Au	197.2	Tellurium . . . .	Te	127.6
Helium . . . . .	He	4.	Terbium . . . . .	Tb	160.
Hydrogen . . . . .	H	1.008	Thallium . . . . .	Tl	204.1
Indium . . . . .	In	114.	Thorium . . . . .	Th	232.5
Iodine . . . . .	I	126.85	Thulium . . . . .	Tm	171.
Iridium . . . . .	Ir	193.	Tin . . . . .	Sn	119.
Iron . . . . .	Fe	55.9	Titanium . . . . .	Ti	48.1
Krypton . . . . .	Kr	81.8	Tungsten . . . . .	W	184.
Lanthanum . . . .	La	138.9	Uranium . . . . .	U	238.5
Lead . . . . .	Pb	206.3	Vanadium . . . . .	V	51.2
Lithium . . . . .	Li	7.03	Xenon . . . . .	Xe	128.
Magnesium . . . .	Mg	24.36	Ytterbium . . . .	Yb	173.
Manganese . . . .	Mn	55.	Yttrium . . . . .	Yt	89.
Mercury . . . . .	Hg	200.	Zinc . . . . .	Zn	65.4
Molybdenum . . .	Mo	96.	Zirconium . . . .	Zr	90.6

**MOH'S SCALE OF HARDNESS.**

The hardness of minerals is most accurately determined by comparison with minerals of known hardness. In making this test, it is important to remember that if one mineral will scratch another, the former has a hardness equal to, or greater than, that of the latter.

Moh suggested that ten more or less common minerals should be used as a scale of hardness, and the species he selected are given below. The units on this scale are not equally spaced — the difference between hardnesses 9 and 10 being as great as the difference between hardnesses 1 and 9 — but the inequalities are not great enough to cause trouble.

**Hardness**

1. *Talc* (foliated, light green).
2. *Gypsum* (Selenite) or *Halite*.
3. *Calcite* (transparent).
4. *Fluorite* (transparent).
5. *Apatite* (transparent).
6. *Orthoclase* (good vitreous lustre).
7. *Quartz* (transparent).
8. *Topaz* (transparent).
9. *Corundum* (cleavable).
10. *Diamond*.

The hardness of the softer minerals can be approximately determined by applying the following facts:

The finger nails will scratch minerals with a hardness equal to, or less than,  $2\frac{1}{2}$ .

A copper coin will just scratch a mineral of hardness 4.

A good knife will scratch minerals with a hardness of  $5\frac{1}{2}$ .

Glass is scratched by minerals over 6 in hardness.

If somewhat porous or granular, a mineral may appear to be much softer than is actually the case. This is noticeable if scratched with a knife or other standard substance. The true hardness may then be determined by scratching a standard substance with the porous mineral.

**VON KOBELL'S SCALE OF FUSIBILITY.**

The fusibility of a mineral can best be tested by placing a fine splinter — held in platinum forceps — in the hottest part of the blow-pipe flame. Six degrees of fusibility can then be recognized, as shown by the following table:

**Degree**

1. *Stibnite*. Coarse splinters fuse very easily.
2. *Natrolite*. Coarse fragments fuse easily.
3. *Almandite Garnet*. Fine fragments fuse easily.
4. *Actinolite*. Fine fragments fuse fairly easily.
5. *Orthoclase*. Fine fragments fuse with great difficulty.
6. *Bronzite or Calamine*. Practically infusible, only the thinnest edges being slightly rounded.



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NOTE: Names of mineral species are in **heavy-face type**, synonyms are in light-face type, and the names of varieties of mineral species are in *italics*.

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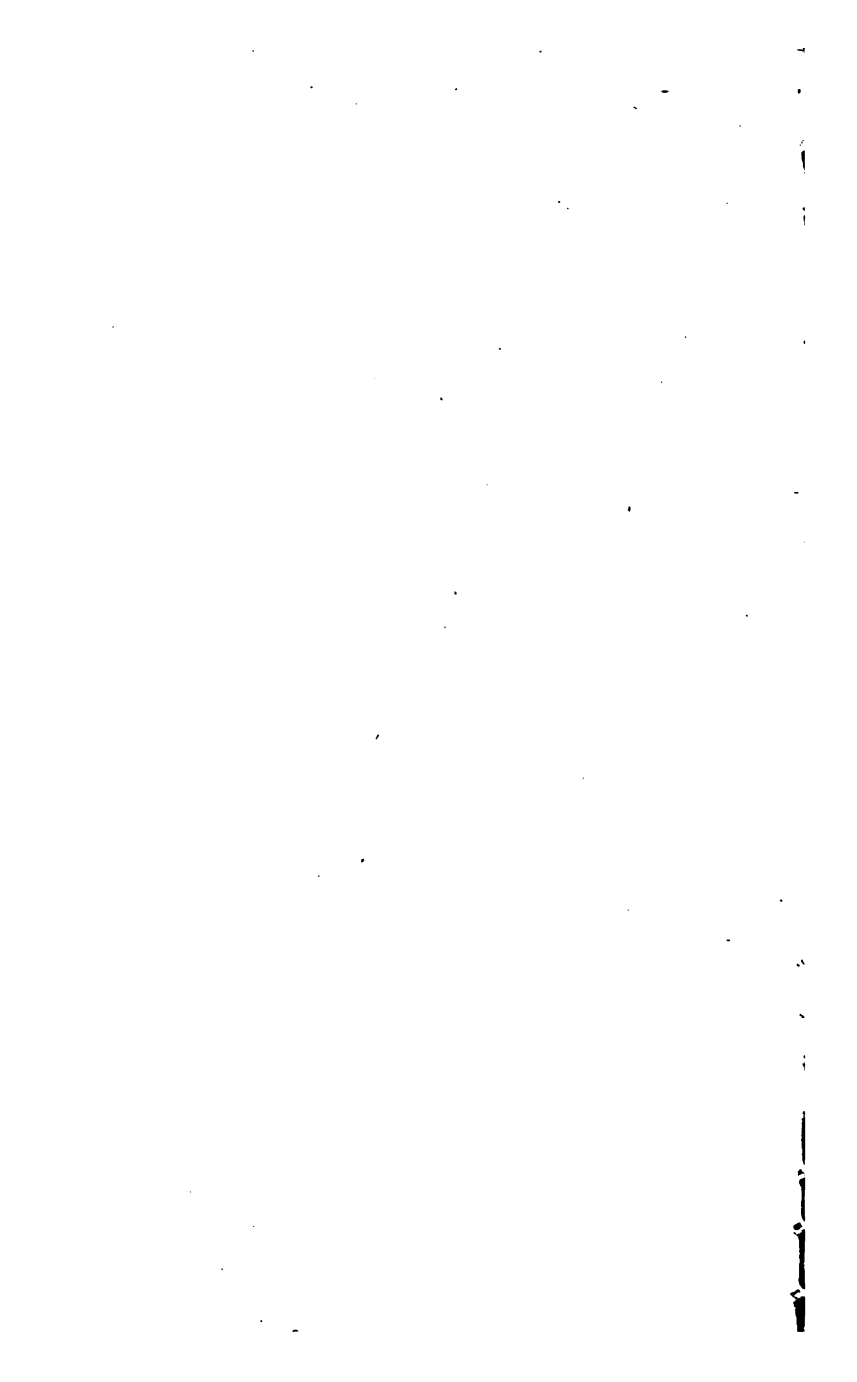
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POCKET HANDBOOK  
OF  
BLOWPIPE ANALYSIS

DESIGNED FOR THE USE OF  
*STUDENTS AND PROSPECTORS WITH THE IDEA OF  
MAKING ORAL INSTRUCTION UNNECESSARY*

BY  
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BY

G. MONTAGUE BUTLER

## PREFACE

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THIS little book was written, primarily, to satisfy the demands of those instructors who have been using the author's Pocket Handbook of Minerals as a text-book for courses in mineralogy. While there is no doubt that a thorough knowledge of the *physical* characteristics of minerals should be the end sought by all teachers and students of this subject, it is often desirable to be able to fall back upon other simple tests in corroboration of conclusions reached by observation, or when studying an unfamiliar mineral. For this purpose, blowpipe analysis is very satisfactory, since the necessary implements and reagents are comparatively few and simple and may be so selected as to be portable.

While there are many works on this subject, they are either too comprehensive for the purpose for which this is intended, or else form merely an introductory chapter to a work on mineralogy. In both cases, their purchase entails a needlessly high expense, and their directions and statements are often so vague and incomplete as to require continual explanation by an instructor.

No originality is claimed for the tests themselves as given in this pamphlet; they are the same as are included in all books on the subject, and as have been taught in the Colorado School of Mines for years by Professor H. B. Patton. Such modifications and additions have been made, however, as experience has proven desirable. The text and plan of the work are, of course, original, and so are most of the data included in the notes on the various tests. Utility and conciseness have been the ends sought, and it is believed that no superfluous details have been included and that nothing essential has been omitted.

Secondarily, the book was written to satisfy the needs of miners and prospectors, whose first question on finding a new mineral is, "What does it contain?" It is so elementary in its nature and the directions are so complete that anyone with a common-school education, the proper instruments, and this book should be able in most cases to answer this question for himself. It was for this class of readers alone that Chapters V and VI were included.

Finally, it is believed that assayers and chemists will find the book useful in making preliminary examinations of unknown substances.



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# BLOWPIPE ANALYSIS

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## CHAPTER I

### BLOWPIPE INSTRUMENTS, REAGENTS, AND OPERATIONS

NEARLY all dealers in assayers' or chemists' supplies carry sets and separate pieces of blowpipe apparatus, and many pieces may be obtained elsewhere, as will be seen from the following brief description of the articles used in the operations later described. Most of the sets now on the market are either too elaborate, too bulky, or else are impractical, and great care should be exercised in their selection.

**Blowpipe.** Many types are manufactured, and each may have its own peculiar advantages, but almost any one in which the aperture is not too large or too small will answer the purpose. The most satisfactory type has a trumpet-shaped mouthpiece, a small chamber in which the saliva may accumulate, and a removable tip. In portable sets it is not practicable to provide a blowpipe with a trumpet-shaped mouthpiece, however, and

this may be dispensed with, although somewhat easier on the lip muscles. Some makes are provided with platinum tips, but this is an unnecessary refinement unless a great deal of work is to be done.

A piece of very fine platinum or steel wire is the best implement with which to clean out a clogged tip.

**Lamps.** It is desirable, although not absolutely essential, to have two lamps, one for oil and the other for alcohol. The latter is handier than the oil lamp for a few operations which will be mentioned later, but in every case it can be replaced by the oil lamp without material disadvantage.

The oil lamp should have a rectangular wick opening about half an inch long and less than half as wide; the wick opening in the alcohol lamp may be of any shape. Care should be taken (particularly with the oil lamp) not to have the wick so tight as to impede the flow of oil, to trim off charred wick or irregularities as fast as they form, and to keep the wick just high enough not to smoke. The best fuel for the oil lamp is a mixture composed of two parts of lard oil and one part of kerosene. This solidifies in very cold weather, but thaws out soon after lighting the lamp.

Any other flame, such as that from a candle or kerosene lamp, may be used instead of these lamps, and it is often necessary to resort to these in the field, but the lamps and oil described will

give the best results in the laboratory. In some places gas blowpipes are used, but one who has attained proficiency with such apparatus is lost in the field, so simpler instruments are preferable.

**Platinum-tipped Forceps.** The most convenient type of these has tips of platinum on one end and of base metal on the other, the platinum-tipped end being provided with a spring which holds the tips together. Precautions as to the use of these forceps are given later. They soon become discolored with use, but, if the precautions just mentioned are observed, this will not harm them. They may be cleaned by using very fine sandpaper or scraping with a knife-blade.

**Platinum Wire and Holder.** The wire should be of about 26 American or B. & S. Wire Gauge in thickness, and should be cut into pieces between two and three inches long. The holder may be a glass tube into which one end of the wire is fused, but a mechanical holder with a hollow handle in which extra wires may be kept is more convenient. Precautions concerning the use of the platinum wire are given later.

**Charcoal Supports.** These should be made from soft wood and should be at least three inches long, preferably more. They should not fissure, break, smoke, or ignite readily in the flame, and should leave little ash when burned.

Unless liquid reagents have been used on the

charcoal in tests resulting successfully, the charcoal may be used many times by scraping off the surface and the deposits formed thereon. Where liquids have been used in successful tests, they are apt to sink for a considerable distance into the charcoal, and to cause a duplication of the test even after a considerable depth of the charcoal has been removed.

**Closed Tubes.** These are usually formed of three-eighths inch glass tubing three or four inches long, an inch of one end being bent to one side and closed by fusion. Equally satisfactory results are secured from an implement formed by fusing together one end of an open tube (see below). Closed tubes cannot well be cleaned and should be discarded after use. A strip of asbestos, or even paper, wrapped around the upper part of the tube makes a convenient holder for hot tubes.

**Open Tubes.** These are pieces of three-eighths inch glass tubing three to five inches long. They should be discarded after use unless the results have been negative, when the other end may be used for a new test. The asbestos or paper holder mentioned above should be used for hot tubes.

**Miscellaneous.** A small slab of hard steel with at least one polished surface for use as an anvil.

A small steel hammer with a flat face.

A small horseshoe or bar magnet. The latter may be procured with one end so shaped as to

form a charcoal borer, but this is not necessary.

Test-tubes.

A hand-lens.

A small piece of dark blue glass.

**Reagent Bottles and Reagents.** Wide-mouth, glass-stoppered bottles are the best in which to keep the dry reagents, which should include powdered (preferably dehydrated) borax, sodium carbonate, sodium ammonium phosphate (salt of phosphorus), acid potassium sulphate, and bismuth flux (equal proportions of potassium iodide and sulphur).

The wet reagents should be kept in glass bottles with glass stoppers, and a dropper stopper will be found a great convenience, although a satisfactory dropper can be easily made from a small glass tube. The following reagents are needed:

Hydrochloric (muriatic) acid. The concentrated acid should be diluted with an equal volume of water for most purposes.

Nitric acid. The concentrated acid is usually employed.

Sulphuric acid (oil of vitriol). For most purposes the concentrated acid should be diluted with four volumes of water. A great deal of heat is generated when water and sulphuric acid are mixed, and this should be done with care. The acid should be added gradually to the water, stirring constantly. Water should *never* be added to sulphuric acid.

Cobalt nitrate. The dry salt should be dissolved in ten parts of water for use.

All acids should be handled with care, as they are more or less corrosive and are capable of inflicting painful injuries when spilled on the skin. When this happens, or if they fall upon fabrics, their effects may be neutralized by moistening with ammonia and then washing thoroughly with water.

**Blowpipe Operations.** The blowpipe is used for the purpose of concentrating the flame into a long, slender cone which can be readily directed against the substance to be heated. It is very important that the blast be continuous and uniform, although this may seem very difficult at first. The blast is not produced by the lungs, but results from a bellows-like action of the distended cheeks. During the operation, air is inhaled only through the nose, and is exhaled largely through the mouth and the blowpipe. Before trying to use that instrument, distend the cheeks, and, keeping the mouth closed, breathe through the nose for a moment; then open the lips just enough to allow a little air to escape slowly, and admit air from the lungs by a kind of gulping action just fast enough to keep the cheeks fully distended. This may take some practice, but, when it is possible to allow air to escape continuously from the mouth in this way no matter whether it is being exhaled or inhaled through the nostrils, it is time to begin to use the blowpipe.



**Producing the Oxidizing Flame.** Place the oil lamp so that the longer dimension of the wick is from right to left, and set its right-hand edge upon a pencil or some other low support so that it will tip somewhat to the left. Insert the tip of the blowpipe about one-eighth of an inch within and just above the right-hand side of the wick, and blow steadily parallel to the wick, directing the flame to the left, and producing a clear blue flame about an inch long. If all of the flame cannot be thus diverted to the left, or if there are yellow streaks in the flame, trim or lower the wick. If the whole flame is inclined to be yellow, move the tip of the blowpipe a trifle to the left. If it is impossible to produce a flame approaching the length mentioned above, the opening in the end of the blowpipe is too small, and this opening is too large when a very long, hissing flame is produced. In order to succeed in blowing a steady flame, the hand must rest upon some support, or the third and fourth fingers may be placed against the lamp.

In analytical operations it is sometimes desirable to oxidize substances to be tested, and at other times the aim is to reduce them to the metallic condition; either result can be more or less readily obtained with the blowpipe.

A flame produced in the manner above described is called an oxidizing flame, but the action of all portions of such a flame is not oxidizing. The blue

cone contains considerable carbon monoxide and is feebly reducing in its action, but just outside of the blue cone at the tip of the flame is an extremely hot but nearly colorless zone which is strongly oxidizing because of the free oxygen there present, and anything held in this zone about a quarter of an inch from the tip of the blue flame will be in the most favorable position for oxidation.

The oxidizing flame is hotter than the reducing, and the hottest part of this flame is just outside of the blue cone. In the absence of other instructions, substances should always be heated there.

**Producing the Reducing Flame.** Hold the tip of the blowpipe about one-sixteenth of an inch above and to the right of the wick, and a long, yellow flame containing much unconsumed carbon will be produced. This is sometimes called the smoky reducing flame. Where greater heat is required, the inner cone of the oxidizing flame should be used. The strongest reducing action will take place at the tip of, and within, the yellow cone of the reducing flame.

**Other Operations.** These will be described in detail when the various tests are discussed.

## CHAPTER II

### METHODS OF TESTING FOR THE VARIOUS ELEMENTS WITH THE BLOWPIPE

THE methods of testing for the various elements with the blowpipe comprise blowpipe analysis, and many tests are included under this term, including a few in which the blowpipe is not required. The most useful are included in the following list, and will be discussed in the order named:

- I. Treatment on charcoal without flux.
- II. Treatment on charcoal with flux.
- III. Tests in closed tubes.
- IV. Tests in open tubes.
- V. Tests with borax beads.
- VI. Tests with salt of phosphorus beads.
- VII. Flame tests.
- VIII. Cobalt nitrate coloration tests.
- IX. Tests with acids.

The tests given should make it possible to recognize the following elements and substances in most of their combinations:

Aluminum (Al), antimony (Sb), arsenic (As), barium (Ba), bismuth (Bi), boron (B), cadmium (Cd), calcium (Ca), chromium (Cr), cobalt (Co),

copper (Cu), fluorine (F), gold (Au), iron (Fe), lead (Pb), lithium (Li), magnesium (Mg), manganese (Mn), mercury (Hg), molybdenum (Mo), nickel (Ni), phosphorus (P), potassium (K), selenium (Se), silver (Ag), sodium (Na), strontium (Sr), sulphur (S), tellurium (Te), tin (Sn), titanium (Ti), tungsten (W), uranium (U), vanadium (V), zinc (Zn), and water, silicates, and carbonates.

### 1. TREATMENT ON CHARCOAL WITHOUT FLUX

A piece, the size of a BB shot or smaller, of the substance to be tested is pressed into the face of the charcoal about half an inch from one end, or it may be placed in a tiny cavity formed at that point, the object of embedding it somewhat in the charcoal being merely to prevent the particle from sliding off or being blown away. The charcoal is then held in the left hand, pointing right and left, and the blowpipe flame is blown upon the particle, which should be at the right end, in such a manner that the flame is not parallel with the charcoal but impinges downward upon the particle at a small angle.

The piece tested is known as the assay.

Heat the assay strongly for a minute or more in the oxidizing flame, noting any odor or colored flame that may be given off, and then examine the charcoal for any coatings, known as sublimates, that

may have been deposited thereon. If no very positive results are thus obtained, repeat the operation, using the reducing flame.

Care must be taken not to place the assay in deep holes that have been burned or scraped into the charcoal. If this is done, the volatilized material will shoot up into the air, and no sublimate will deposit on the charcoal.

Most charcoal forms a little white ash when burned; this should not be confused with a sublimate.

Decrepitation (flying to pieces) of the assay may sometimes be prevented by heating it very slowly, i.e., holding it three or four inches from the flame at first and gradually bringing it nearer. Another method, often satisfactory, consists of blowing the flame against the upper part of the end of the stick of charcoal until it is red hot, thus gradually warming the assay.

If the substance still decrepitates or if no results are obtained by the above methods of treatment, powder the material to be tested *very fine* and press a small amount of the powder onto one end of the charcoal, using a knife blade or spatula for this purpose and forming a flat cake of the powder. Then proceed as before. If the material still decrepitates, moisten it with water and heat very slowly.

Since chlorides of lead, copper, and other sub-

stances yield white sublimates on charcoal that may be confused with those mentioned below, it is essential that the charcoal tests be made before any hydrochloric acid has been put on the substance to be tested.

Not only is it necessary to note the color of any sublimates produced, but their volatility should also be tested, as some are very volatile (can be burned off by applying the blowpipe flame for a fraction of a second) while others are quite non-volatile (require the application of considerable heat to entirely remove them) in the oxidizing flame, which should be used for this test.

The results obtained by any of the above means may be thus interpreted:

- a. White, very volatile, light sublimate, deposited some distance from the assay. Strong odor of garlic ..... As
- b. White sublimate with a blue border deposited close to the assay, heavier and less volatile than that yielded by As. Assay will often continue to give forth white fumes after heating has ceased ..... Sb
- c. White, fairly easily volatilized, heavy sublimate near the assay, shading into a lighter, more volatile coating further out. Odor of garlic ..... Sb with As

- d. White and yellowish, crystalline (particles are coarse and sharp-edged) sublimate which is changed to a deep ultramarine blue if touched for a *fraction of a second* with the reducing flame. A copper-red coating may form close to the assay ..... Mo

(Prolonged heating with the oxidizing flame is required to obtain the white sublimate, which is yielded satisfactorily only by the sulphide—molybdenite.)

- e. White when cold, yellow when hot, light, non-volatile sublimate, which, if moistened with cobalt nitrate and heated, will become bright green when cold..... Zn

(This test should be conducted as follows: Pulverize the material very fine and heat strongly and for some time with the reducing flame; moisten the charcoal where the sublimate has formed, or should form, with a little cobalt nitrate; reheat the assay strongly with the reducing flame, and, if Zn be present in any form but the silicate, enough heat will reach the spot moistened to turn it bright green when cold.)

- f. White, heavy sublimate with a blue outer border close to the assay, a yellowish gray coating far from the assay, and a black band between the two. All are easily volatile, burning off with a light bluish green flame, which is also yielded by the assay Te
- g. White when cold, yellowish when hot, light,

non-volatile sublimate, which, if moistened with cobalt nitrate and heated, will become a dull bluish green when cold..... Sn

(This test should be conducted exactly like the one for Zn, described above.)

- h.* Yellow, volatile sublimate, inclining toward orange when hot, with a very volatile outer fringe of white. Yellow fumes and odor of garlic.... As with S

(This result is obtained when a sulphide of As is heated and volatilized too rapidly to permit of complete oxidation. Some of the material is volatilized and deposited as the yellow sulphide of As.)

- i.* Yellow or orange, non-volatile sublimate, often with a bluish white outer border, deposited very close to the assay..... Pb

- j.* Yellow or orange, non-volatile sublimate, often with a bluish white outer fringe, deposited very close to the assay..... Bi

(Bi is much rarer than Pb, and the test described above may in the majority of cases be interpreted as indicating Pb. To distinguish with certainty between these two elements, mix the powdered substance with three or four times its volume of "bismuth flux" (equal proportions of potassium iodide and sulphur), and heat on charcoal as usual. The sublimate produced by Bi will be yellow near the assay, but bordered on the outer edge by a brilliant red, which will be missing in the case of Pb.)

- k.* Brown, volatile sublimate close to the assay,



bordered by a very volatile, heavy white sublimate. Odor of garlic..... As

(This result is obtained when the material is heated and volatilized too rapidly to admit of complete oxidation of the As. The brown sublimate is metallic As.)

*l.* Brown, fairly volatile sublimate close to the assay ..... Cd

*m.* Reddish brown outer border on a black or steel-gray volatile sublimate. A curious and indescribable, but characteristic, odor and a blue flame..... Se

*n.* Lilac or lilac-red, volatile sublimate...Ag with Pb  
(Ores yielding this result are rare.)

*o.* Blue flame and a suffocating pungent odor... S  
(Se, Te, Cu chloride, and other substances burn with a blue flame, but the blue flame combined with the odor is distinctive of S.)

*p.* Magnetic residue left on charcoal...Fe, Ni, or Co  
(If the assay is infusible—does not melt—a magnetic residue indicates Fe.)

## II. TREATMENT ON CHARCOAL WITH FLUX

This test is used when it is desired to reduce a salt to the metallic condition, so the reduction flame is employed.

The substance to be tested is finely pulverized and mixed thoroughly with about three times as

much powdered sodium carbonate and a little powdered borax. The mixture is then pressed into a cake at one end of the charcoal and thoroughly fused, beginning at the edges and working toward the center. A little powdered charcoal thoroughly mixed with the material to be fused will often facilitate the reduction. If the assay will not fuse down to a liquid mass, either the amount of flux (sodium carbonate and borax) or of heat applied is deficient. In the latter case, raise the lamp wick and trim off the coal that forms upon it. It is almost useless to hope for satisfactory results until a continuous blast can be blown. Sometimes a fusion that appears to have come to a standstill may be successfully completed by allowing the assay to cool, removing the little cake of semi-fused material with the point of a knife, turning it upside down on the charcoal, and proceeding as at first. Some charcoal usually adheres to the upper surface of the cake and this has a strong reducing influence. This process is always necessary in the case of Sn.

Metallic Sb and many sulphides and arsenides yield metallic globules by this test, but these are distinguishable by their brittleness from those described below.

In addition to sublimates identical with those that form on charcoal without flux, other results are produced which may be thus interpreted:

- a. White when cold, yellow when hot, light, non-volatile sublimate, which, if moistened with cobalt nitrate and heated, will become bright green when cold. . . . . Zn

(Zn compounds which give this test with difficulty or not at all when treated without flux will give a good color when flux is used. The operation should be conducted as described under I.e. Care should be exercised not to confuse the *green* Zn coloration that appears *in front of the assay* with a *blue* color *on the assay* itself. The latter will appear whenever fusible material is moistened with cobalt nitrate and heated, regardless of the presence or absence of Zn.)

- b. Lilac or lilac-red, moderately volatile sublimate and a white, malleable, metallic button . . . . . Ag with Pb

(Ores yielding this result are rare.)

- c. Yellow or orange, non-volatile sublimate, often with a bluish white outer border, deposited very close to the assay, and a malleable, metallic button, grayish white on a freshly cut surface but oxidizing on exposure to the air. . . . . Pb

- d. Yellow or orange, non-volatile sublimate, often with a bluish white outer border, deposited very close to the assay, and a rather brittle, metallic button, grayish white on a freshly cut surface but oxidizing on exposure to the air. . . . . Bi

(The button may flatten somewhat when first hammered but is not malleable like Pb. This will

usually suffice to distinguish between the two metals, or the test with "bismuth flux," described under I.f., may be applied.)

e. White, malleable, metallic button..... Ag

(To distinguish between Ag and Pb buttons, place the button to be tested in a small depression on a clean piece of charcoal and heat strongly in the oxidizing flame. If Pb, the characteristic yellow sublimate will form, and, if Ag, there will be no coating or only a faint brownish one. The two metals may also be distinguished after some practice by the fact that the Ag is decidedly harder; the flattened button may be cut only with difficulty while Pb cuts easily.)

f. White, malleable, metallic buttons of small size, which show little or no tendency to coalesce into one large button. A white when cold, yellowish when hot, light, non-volatile sublimate may also form..... Sn

(To distinguish between Sn and Ag, remember that the latter forms one large button, usually, while the many small buttons of the former can be forced to coalesce only with great difficulty and after prolonged blowing. Another method of distinguishing them is to alloy the button in doubt with a somewhat smaller amount of Pb, by melting the two together, and then to note whether the characteristic lilac Ag-Pb sublimate is produced in the oxidizing flame. A third method involves an endeavor to secure the sublimate and cobalt nitrate color reaction of Sn as described under I.g.)

g. Yellow, malleable, metallic button..... Au

h. Red, malleable, metallic mass, which it is

- impossible to fuse into a single button by means of the blowpipe..... Cu
- i. Gray, malleable, magnetic particles (not globules).....Fe, Co, or Ni
- (The three may be readily distinguished by the "bead tests" (V.), q.v.)
- j. The thoroughly fused mass forming the assay, when placed on a clean, moistened silver surface, produces a dark brown or black stain .....S, Te, or Se

(This test is very delicate, but it must be made carefully in order to succeed. *Exactly* three parts by volume of sodium carbonate must be used for one part of the substance to be tested, and it is best to press the fused mass with a knife or hammer-head against the silver surface which has previously been moistened with a drop of water, and to hold it there for a minute or two. Sometimes a slight stain which may be rubbed off with the fingers or washed off with water is produced. This should be ignored, as the S, Te, or Se stain is permanent.

Unless Te or Se have been detected by tests I.f., I.m., III.c., III.f., III.l., III.o., IV.g., or IV.k., the presence of a dark stain on the silver may be assumed to indicate S.)

### III. TESTS IN CLOSED TUBES

It is sometimes desirable to treat the substance just as it is, while for other tests it is best to mix it with three or four times as much sodium carbonate or acid potassium sulphate. In any case, the whole charge should be powdered as fine as possible and

enough introduced within a tube to fill it to a height of about half an inch. This may be done with a small paper or tin funnel or chute, or even with a very small knife-blade.

The lower portion of the tube and the charge contained therein should then be heated to redness for some time and the results noted. An alcohol flame alone may be used for this purpose, but the work may be hastened and the results often improved by using the blowpipe on the alcohol or oil flame. Care must be exercised not to use too high a heat or the glass will melt, swell, and break open, or will completely seal up the charge.

Possible results obtainable *without flux* are as follows:

- a. Moisture in drops on the walls of the tube a short distance above the charge.....  $H_2O$
- b. Liquid, mirror-like sublimate that collects in globules ..... Hg  
(Only the native metal will give this result without using sodium carbonate flux.)
- c. Mirror-like sublimate of large and small, solid, white globules..... Te
- d. Mirror-like sublimate of very small, solid, white globules ..... Cd  
(Cd and Te are easily distinguished by using tests I.f. and I.l.)
- e. Mirror-like, solid, black sublimate, often with dull black sublimate above, both volatile As

(A sulphide will not yield this result without using sodium carbonate flux.)

- f.* White sublimate composed of tiny globules in a narrow zone immediately above the charge, with a ring of yellow globules or liquid at the base, both very slowly volatile..... Te

(Tests III.*c.* and III.*f.* are given by different ores of Te or are the result of the application of different temperatures.)

- g.* White, faint, very slowly volatile sublimate with a little yellow liquid close to the charge..... Sb

(A sulphide will not yield this result without using sodium carbonate flux.)

- h.* Reddish liquid when hot, yellow solid when cold; may be almost white when cold if the amount is small..... S

- i.* Dark red liquid when hot, orange solid when cold..... As with S

- j.* Black when hot, reddish brown when cold, difficultly volatile sublimate .....Sb with S

- k.* Black, volatile sublimate. If the tube is broken and the sublimate rubbed with a cloth, it will sometimes turn red, but this is unusual.....Hg with S

- l.* Black, difficultly volatile sublimate, composed of irregularly shaped drops, liquid when hot. Shades above into a volatile sublimate,

reddish brown when hot and dark red when cold . . . . . Se

*Possible results obtainable with sodium carbonate flux are as follows:*

- m.* Moisture in drops on the walls of the tube  
a short distance above the charge . . . . . H<sub>2</sub>O
- n.* Liquid, mirror-like sublimate that collects  
in globules . . . . . Hg
- o.* Mirror-like sublimate of large and small,  
solid, white globules . . . . . Te
- p.* Mirror-like sublimate composed of very small,  
solid, white globules . . . . . Cd  
(Cd and Te are easily distinguished by using  
tests I.f. and I.l.)
- q.* Mirror-like, solid, black sublimate, often  
with a dull, solid, black, sublimate above,  
both volatile . . . . . As
- r.* White, faint, very slowly volatile sublimate  
with a little yellow liquid close to the  
assay . . . . . Sb

*Possible result obtainable with acid potassium sulphate is as follows:*

- s.* After boiling the contents of the tube vigorously for several minutes, the glass immediately above the charge is etched or roughened . . . . . F  
(This result is most easily recognized by breaking



the tube, washing the interior thoroughly, and then scratching the portion that may be etched with the point of a knife. If etching has occurred, the surface will feel much rougher than does unetched glass.)

#### IV. TESTS IN OPEN TUBES

No flux is used in these tests. The substance to be treated is merely finely powdered, a little of it is placed about half an inch from one end within a tube, and it is then heated strongly while the tube is held as highly inclined as is possible without losing the charge. The alcohol flame may be used, but as good or better results are produced by the oil flame and the blowpipe. In fact, the greater heat of the blowpipe-concentrated oil flame is essential for some of the tests, and this should always be used after securing negative results with the alcohol flame.

The tests are very delicate, but are ordinarily used only to corroborate unsatisfactory charcoal tests.

Possible results may be thus interpreted:

- a. Moisture in drops on the walls of the tube..  $H_2O$
- b. Characteristic, suffocating, pungent odor... S  
(Many sulphides fail to yield this test.)
- c. White, light, very volatile, crystalline sublimate, and odor of garlic..... As
- d. White, heavy sublimate, less volatile than

that given by As, and dense white fumes. Slender white crystals may form on the charge if the heat is not too great..... Sb

- e. White when cold and light yellow when hot, very heavy, almost non-volatile sublimate and very dense white fumes which pass along the under side of the tube. If a large amount of material be heated very intensely, a little difficultly volatile sublimate, black when hot and reddish brown when cold, may form .....Sb with S
- f. White, faint, non-volatile sublimate close to charge . . . . .Pb with S
- g. White, slowly volatile sublimate, which fuses to globules which are yellow hot and colorless cold. Often, yellow globules form around, and a gray sublimate collects above the charge ..... Te
- h. White, non-volatile sublimate, fusible to yellow drops, lighter when cool . . . . .Bi with S  
 (Bi with S and Te are readily distinguished by tests I.f. and I.j., the latter being characteristic of Bi no matter in what combinations it may be.)
- i. White, delicate crystals, yellow when hot, form near and over the charge after prolonged heating..... Mo  
 (This result is yielded only by the sulphide.)
- j. Yellow, volatile sublimate, inclining toward orange or red when hot, with a very volatile

outer border of white. Yellow fumes and odor of garlic . . . . . As with S

(This result is often produced when a substance containing S and As is heated too rapidly to allow of complete oxidation.)

k. Black, volatile sublimate where very heavy, which shades toward the upper end of the tube into a volatile coating that is reddish brown when hot and dark red when cold. A curious and indescribable but characteristic odor and lilac fumes, best seen against a black background . . . . . Se

l. Black, very volatile sublimate with brownish or iridescent bands and sometimes a mirror-like deposit close to the charge. White fumes, a white volatile sublimate beyond the black, and characteristic odor of garlic. As

(This result is produced when a large amount of material is heated too rapidly to allow of complete oxidation.)

## V. TESTS WITH BORAX BEADS

The beads are made by heating the end of a platinum wire to redness, dipping it into some powdered or granulated borax, reheating the wire and adhering borax, and continuing the process until the bead when thoroughly fused is as large as will remain on the wire. If too small, the color is hard to see, and a bead that is too large will keep

falling from the wire. Some of the oxidizing flame tests may be made with the alcohol flame, but all may be secured more quickly and easily with the oil flame and the blowpipe.

The bead should always be kept at the end of the wire, and this may be done by bending the end of the wire and holding it in such a manner that the blowpipe flame is always directed against the side of the bead furthest from the end, forcing it to the end. A loop to hold the bead should not be formed in the wire; it is unnecessary if the wire is clean, and uses up the platinum very rapidly.

Before making any bead test, the material to be tested should be powdered and thoroughly roasted on charcoal. This is accomplished by spreading the powder on the surface of the charcoal in a flat cake, so as to allow free access of air, and heating to a dull red in that part of a small oxidizing flame that is well outside of the blue cone. The reducing flame should then be applied, and, finally, the oxidizing flame used until no odors of As or S are apparent and the assay ceases to burn with a colored flame or to volatilize. Fusion should be prevented if possible. This may be accomplished by mixing the fusible substance with about an equal volume of powdered charcoal, which keeps the particles separated and soon burns away. No satisfactory bead tests need be expected from a substance which volatilizes completely without solidification.

To make the tests, heat the bead as hot as possible and touch it to a very little (a few grains) of the powdered substance to be tested. Some of the latter will adhere to the bead, which should then be heated in the oxidizing flame and any resulting change of color noted. This process should then be repeated on the same bead, using the reducing flame. If the results are negative or too faint to be decisive, more of the powder should be dissolved in the bead and the process continued until a relatively large amount has been added, when the bead is said to be saturated.

The colors of the beads are due to the presence of oxides of the various elements, and these oxides vary greatly in their coloring powers. In some cases, deep, vivid colors are obtained from a few grains of the powdered substance, while in other instances it is necessary to dip the bead many times into the powdered substance before the characteristic colors are produced. Beads in the former class may be considered saturated when the color is so deep as to make them practically opaque; those in the latter class are saturated when they refuse to absorb more of the material. This may require half a dozen applications of the powder.

In case a bead becomes so saturated upon the first application to the powder that its color is indeterminate, it may be flattened upon the anvil while still warm and the color readily observed in

the thin cake thus formed. This cake may then be broken into many pieces, and a few of these added to a fresh bead without saturating the latter. All beads, even when saturated, should be perfectly clear unless otherwise noted. If this is not the case, a higher heat should be applied or new beads formed, as a bead that has been worked with for some time in different flames is apt to become translucent or opaque.

It should be remembered that a bead containing incompletely roasted powder is very apt to be brown in both flames, and then prolonged heating is required to expel the S or other interfering element or elements.

The bead test should never be used on a substance suspected to contain Cu, as that element will alloy with the platinum and give Cu beads whenever the same wire is used in subsequent tests. Other elements are apt to alloy with the platinum, particularly during the formation of reduction beads, and these will make the wire brittle and cause it to break easily, but will not interfere with tests made before the break occurs.

To remove a bead from the wire, either break it off on the anvil or jar it off while in a molten condition. When the latter method is used, it is a good idea to save the beads obtained from known substances and compare them with those given by unknown materials.

The most difficult operation involved in making the bead tests is the production of a good, continuous reducing flame, yet this is very important and must be mastered. Manganese gives a very highly colored bead in the oxidizing flame, and the production of the colorless bead in the reducing flame is a good test of ability in this line.

If a substance contains two elements each of which yields a characteristic bead, one may so modify the other as to give intermediate results. However, in most cases of this kind, one color will completely mask the other, and this makes it then impossible to detect both elements.

The accompanying table indicates the colors of the borax and salt of phosphorus beads (see below) yielded by the elements named in both oxidizing and reducing flames. The following abbreviations are used: O.F.=oxidizing flame. R.F.=reducing flame. W=warm bead. W\*=saturated warm bead. C=cold bead. C\*=saturated cold bead.

As an illustration, consider iron. The table shows that iron gives in the oxidizing flame a borax bead that is yellow while warm and colorless when cold unless the bead is saturated; then, it is yellow when cold. In the reducing flame, the bead is green when warm and colorless when cold unless saturated, when it is bottle-green when cold. Likewise, both the non-saturated and saturated salt of phosphorus beads are yellow when warm and

# BLOWPIPE ANALYSIS

	Colorless.	Yellow.	Green.	Blue.	Violet.	Red.	Brown.	Refer- ences.
a. Iron.....	O.F. R.F. C	W*WC*	W*WC*					NOTE 1
b. Molybdenum.....	O.F. R.F. C*C WC	W*W					W*C*	NOTE 2
c. Titanium.....	O.F. R.F. C	W*WC* W*WC*						
d. Tungsten.....	O.F. R.F. WC*C WC*C	W* W*						
e. Uranium.....	O.F. R.F. C	W*WC* W*W	C*					
f. Vanadium.....	O.F. R.F. C	W*WC*	W*WC*C					NOTE 3
g. Chromium.....	O.F. R.F.	W	C*C W*WC*C			W*		NOTE 4
h. Copper.....	O.F. R.F.		W*W W*W	C*C C*C		C*		NOTE 5
i. Cobalt.....	O.F. R.F.			W*WC*C W*WC*C				NOTE 6
j. Manganese.....	O.F. R.F.				W*WC*C			NOTE 7
k. Nickel.....	O.F. R.F. WC				W*W		C*C	NOTE 8



## NOTES ON TABLE OF BORAX BEAD TESTS

NOTE 1. The strongly saturated bead is a dull bottle- or olive-green when cold after treatment with the reducing flame. A very small quantity of ore should be used for the unsaturated bead tests.

NOTE 2. The strongly saturated bead is opaque after treatment with the reducing flame.

NOTE 3. Saturated and non-saturated warm beads are greenish yellow after treatment in the oxidizing flame.

NOTE 4. The cold, non-saturated bead is yellowish green after treatment with the oxidizing flame. A small quantity of ore should be used for the unsaturated bead tests.

NOTE 5. The strongly saturated bead may be opaque and dark brownish red after treatment in the reducing flame. A very small quantity of ore should be used for the unsaturated bead tests.

NOTE 6. A very small quantity of ore should be used for the unsaturated bead tests.

NOTE 7. An extremely small quantity of ore should be used for the unsaturated bead tests.

NOTE 8. The saturated bead is gray and opaque after treatment with the reducing flame.

### NOTES ON TABLE OF SALT OF PHOSPHORUS BEAD TESTS

NOTE 1. The warm bead is pale to deep yellowish green (depending upon the degree of saturation) after treatment with the reducing flame. A very small quantity of ore should be used for the unsaturated bead tests.

NOTE 2. The cold saturated bead is very pale violet after treatment with the reducing flame.

NOTE 3. The cold saturated bead is greenish blue after treatment with the reducing flame.

NOTE 4. The green bead obtainable with the reducing flame cannot be reoxidized to yellow.

NOTE 5. A small quantity of ore should be used for the unsaturated bead tests.

NOTE 6. The cold non-saturated bead is pale green after treatment with the reducing flame.

NOTE 7. The strongly saturated bead may be opaque and dark brownish red after treatment in the reducing flame. A very small quantity of ore should be used for the unsaturated bead tests.

NOTE 8. A very small quantity of ore should be used for the unsaturated bead tests.

NOTE 9. An extremely small quantity of ore should be used for the unsaturated bead tests.

TABLE OF SALT OF PHOSPHORUS BEAD TESTS.

	Colorless.	Yellow.	Green.	Blue.	Violet.	Red.	Brown.	Refer- ences.
a. Iron.....	O.F. R.F. C*C C	W*W	W*W				C*	NOTE 1
b. Titanium.....	O.F. R.F. C*C C	W*W W*W			C*			NOTE 2
c. Tungsten.....	O.F. R.F. WC*C WC	W* W*		C*				NOTE 3
d. Vanadium.....	O.F. R.F.	W*WC*C	W*WC*C					NOTE 4
e. Nickel.....	O.F. R.F.	C*C C*C				W*W W*W		
f. Chromium.....	O.F. R.F.	W	W*C*C W*WC*C					NOTE 5
g. Uranium.....	O.F. R.F.	W*W	C*C W*WC*C					
h. Molybdenum.....	O.F. R.F. C		W*WC* W*WC*C					NOTE 6
i. Copper.....	O.F. R.F.		W*W W*W	C*C C*C		C*		NOTE 7
j. Cobalt.....	O.F. R.F.			W*WC*C W*WC*C				NOTE 8
k. Manganese.....	O.F. R.F. W*WC*C				W*WC*C			NOTE 9

colorless when cold in the oxidizing flame, while in the reducing flame the non-saturated salt of phosphorous bead is pale yellowish green when warm and colorless when cold, and the saturated bead is deep yellowish green when warm and brown when cold.

#### VI. TESTS WITH SALT OF PHOSPHORUS (SODIUM AMMONIUM PHOSPHATE OR MICROCOSMIC SALT) BEADS

These tests are made in exactly the same manner as are those with borax beads and the same precautions should be observed. The salt of phosphorus is, however, much more liquid than borax, especially when first heated, and drops off the wire very easily. It will be found necessary to build the bead up gradually by the addition of small particles picked up on the hot wire one after the other and to use smaller beads than with borax. If difficulty in retaining the bead is still experienced, it will be found advisable to form a loop in the end of the wire by bending it around the point of a lead pencil. In any case, it is best while forming the bead to allow the flame to play upon the under side of the fusing mass, thus buoying it upward and decreasing its tendency to drop off.

The salt of phosphorus tests are necessary for

the recognition of some of the elements, but in most cases they will be found useful merely to corroborate unsatisfactory borax bead tests, and they may often be omitted.

The accompanying table indicates the colors of both salt of phosphorus and borax beads in both oxidizing and reducing flames. The abbreviations and use of the table have been explained in the discussion of the tests with borax beads.

## VII. FLAME TESTS

When volatilized, certain substances impart more or less decided colors to a flame, and the recognition of these colors constitutes distinctive tests for such elements.

The flames are best seen in a dark room or against a dark background, and even then it requires close application to perceive the very brief flashes of color which constitute the tests in many instances.

Four different methods of making these tests may be used, and they should be applied in the order given, it being unnecessary, however, to seek further results after a determination has been made by any of the methods. If two elements, both of which yield characteristic flames, are present, one will usually so mask the other as to make the recognition of both impossible.

The second, third, or fourth method should never be used upon a substance with a metallic

lustre without a thorough preliminary roasting, as As, Sb, Pb, and other easily reduced elements, are apt to form fusible alloys with the platinum wire or forceps and thus ruin them.

Some elements yield their characteristic flame colors best at a low heat while others require the highest heat available, so it is always best to use both low and high temperatures for each test.

Some substances which ordinarily yield no flame tests may have some of their constituents converted into volatile, flame-tinting compounds by treatment with some reagent, usually HCl or  $\text{H}_2\text{SO}_4$ . In fact, it is a safe practice always to dampen the material to be tested with HCl, not even trying a test without the use of that acid. If no tinted flame results,  $\text{H}_2\text{SO}_4$  should be tried.

**First Method.** Place a fragment or some of the powdered substance upon charcoal, moisten with a few drops of concentrated HCl, and heat in the hottest portion of the blowpipe flame. The only result that need be sought and noted (the others being more easily obtained, or the elements being more easily recognized, by other methods) is the following:

- a, Azure-blue flame, with or without flashes,  
or a border, of emerald green..... Cu

(If this test results favorably, care should be taken  
not to make the bead tests, which could only

yield Cu, or to heat the material in the platinum forceps, since in either of these operations the Cu will alloy with the Pt and ruin it.)

**Second Method.** (This is applicable only to carbonates. See IX.b.) Seize a sliver of considerable size in the platinum forceps, moisten it with *dilute* HCl (one part of acid to three or four parts of water), and hold the particle near the base of the flame of an alcohol lamp, the blowpipe flame not being used for this test. If the result is negative, repeat the operation, but use the hot tip of the alcohol flame instead of the base. In a few cases, cold or hot concentrated acid is required and these should be tried as a last resort, but the dilute acid should be first tried, as there are several substances which will not give a good reaction with the strong acid.

The splinter should be moistened by immersing it in the acid and holding it there until there is a vigorous effervescence (evolution of gas). Pure, fresh alcohol and acids should be used for these tests, as otherwise a yellow Na flame is apt to be very prominent and may mask the flames yielded by Ba or Pb.

If an alcohol lamp is not available, all of the tests described below may be obtained by using the method next given, but the results are more vivid and are easier obtained in the manner just described, if the substance tested is a carbonate.

Possible results may be thus interpreted:

b. Scarlet flame, lilac through blue glass..... Sr

(A Li flame might easily be confused with that from Sr, but no known Li carbonate occurs in nature, so this test when obtained in the above described manner always indicates the presence of Sr.)

c. Yellowish red flame, greenish through blue glass..... Ca

(This is difficult to distinguish at first from the Sr flame, but is considerably less vivid and is inclined toward orange. It may be positively identified by the fact that Ca salts give good tests no matter whether dipped in concentrated or dilute acid and *dilute* acid *must* be used to secure a good Sr flame.)

d. Yellow flame..... Na

(This test is too delicate to be used with safety unless very intense and persistent. Specimens that have been handled will become sufficiently charged with Na from the fingers to give a good flame test.)

e. Yellowish green flame, pale tint..... Ba  
(Masked by strong Na flame.)

f. Blue flame, pale tint..... Pb

(Hot, concentrated acid is required for this test, and even then the color will appear for only an instant when the splinter is held in the tip of the flame.)

*Note.* A vivid Cu flame may be obtained in this manner, but this should never be attempted, as the forceps will thereby be ruined.

**Third Method.** Hold an extremely fine splinter



(as slender as a very fine needle) in the platinum forceps, moisten it with a drop of  $\text{HCl}$ , and introduce it into the hottest part of the blowpipe flame. A flash or a continuous appearance of color may be imparted to the flame. If the result is negative or unsatisfactory, remoisten the splinter and reheat. If this fails, repeat the operation with  $\text{H}_2\text{SO}_4$  instead of  $\text{HCl}$ . Should the splinter decrepitate, try heating it very slowly, and, if it still flies to pieces, the fourth method must be used.

Possible results may be thus interpreted:

g. Carmine flame, violet through blue glass..... Li

h. Scarlet flame, lilac through blue glass..... Sr

(The colors of the Li and Sr flames are so similar that they are easily confused, but they may be readily distinguished by the fact that a substance that has been ignited and has given a Sr flame will turn moist red litmus paper blue when crushed and placed upon it. Li minerals show no effect of this kind.)

i. Yellowish red flame, greenish through blue glass..... Ca

(This is difficult to distinguish at first from the Sr or Li flames, but is considerably less vivid than either and is inclined toward orange.)

j. Yellow flame..... Na

(This test is too delicate to be used with safety unless very intense and persistent. Specimens that have been handled will become sufficiently charged with Na from the fingers to give a good flame test.)

- k.* Yellowish green flame, pale tint..... Ba  
(Masked by strong Na flame.)
- l.* Bluish green flame, pale tint..... P  
( $\text{H}_2\text{SO}_4$  must be used for this test and the result is not usually very satisfactory.)
- m.* Bright green flame... B  
(B minerals which do not give a flame test in this way should be powdered and mixed thoroughly with about three volumes of a mixture of equal parts of powdered acid potassium sulphate and calcium fluoride—fluorite. This should be introduced into the flame as described in the fourth method.)
- n.* Blue flame, pale tint..... Pb
- o.* Blue flame, pale tint..... Sb  
(The reducing flame must be used to obtain this result, which is neither very satisfactory nor determinative. Care should be taken not to test an Sb ore in this way, as it is apt to alloy with, and ruin, the platinum forceps.)
- p.* Violet flame, violet through blue glass..... K  
(This is difficult to obtain in most cases and is entirely masked by a pale Na flame. The latter is, however, entirely absorbed by blue glass, which transmits the K flame as of lilac or violet color, depending upon the shade of the glass.)

*Note.* A vivid Cu flame may be obtained in this manner, but this should never be attempted, as the forceps will thereby be ruined.

**Fourth Method.** Powder the material to be tested very fine, pick up a little of this powder upon

a flattened platinum wire moistened with HCl, and introduce the powder-coated wire into the hottest part of the blowpipe flame. Momentary flashes or continuous appearances of color may be imparted to the flame, which are to be interpreted as under the third method. If the results are negative, repeat the operation, using  $\text{H}_2\text{SO}_4$  instead of HCl.

This method is not usually very satisfactory and should not be used unless it is impossible to obtain a splinter fine enough to be tested by the third method. Minerals which decrepitate badly, which are very soft, or which occur as a powder must, of course, be tested by this last method.

### VIII. COBALT NITRATE COLORATION TESTS

To make these tests, hold a small splinter of the substance to be tested in the platinum forceps and heat it in the blowpipe flame to the highest possible temperature. Then examine it with a lens; if it shows any signs of fusion, this test cannot be applied. If non-fusible, moisten it with cobalt nitrate and ignite strongly in the hottest part of the blowpipe flame. It will first turn black but after prolonged heating may assume a characteristic tint. If a splinter of the substance cannot be obtained, it should be powdered and the test conducted upon a flat cake of the powder upon charcoal. Longer

heating is required by this method, however, and the results are not apt to be as satisfactory.

This test can be applied only to non-fusible, white or faintly tinted minerals, or those which become white or faintly tinted upon ignition.

Possible results may be thus interpreted:

*a.* Blue coloration.....Al or Zn silicate

(Al minerals and Zn silicate give identical results by this test. If Zn has been obtained by tests I.e., or II.a., it is impossible to test for Al in this way. If Zn is not present, this test may be interpreted as indicating the presence of Al. Occasionally a little green forms with the blue on Zn silicates, which never happens in the case of Al minerals.)

*b.* Green coloration, dark..... Sb

*c.* Green coloration, bright tint, best seen when  
cold . . . . . Zn

*d.* Pinkish or flesh-tint coloration..... Mg

## IX. TESTS WITH ACIDS

These are really purely chemical and should not be included under blowpipe analysis, but two are so simple and useful that they are given below.

- a.* The finely powdered material, when boiled almost to dryness in concentrated nitric acid, yields a gelatinous mass.....a silicate.
- b.* The powdered material effervesces vigorously

when placed in a test-tube containing some condition of hydrochloric acid . . . . . a carbonate

(In some cases the tests appear in cold, dilute acid, while, in other instances, hot dilute, cold concentrated, or hot concentrated may be required. It is best to experiment with the dilute acid first, and then, if results are negative, to increase the temperature until all conditions of acid have been tried.

It is not always necessary to powder the material to be tested, but this is sometimes required and never does any harm.

Care should be taken not to confuse effervescence (escape of  $\text{CO}_2$ ) with boiling (escape of steam) when boiling acid is used.

Some sulphides may effervesce in hydrochloric acid, but these may be distinguished from carbonates by the fact that they yield a gas ( $\text{H}_2\text{S}$ ) that smells like bad eggs.)

## CHAPTER III

### OUTLINE FOR QUALITATIVE BLOWPIPE ANALYSIS

BLOWPIPE analysis is ordinarily used for the purpose of ascertaining what elements an unknown substance contains, this process being known in chemistry as qualitative analysis. It is not possible, excepting in a few cases and by the application of very refined methods not here discussed, to determine how much of an element is present—to make a quantitative analysis of the substance; but, if the elements present are known, it is usually possible to determine the nature of the substance by applying the principles set forth in Chapter V. Where the nature of a mineral has thus been determined, it is comparatively easy to compute the percentage composition with considerable accuracy in many cases, by applying the principles presented in Chapter VI. A tabulation of the principal elements present in many common minerals are given in Chapter V. Even when the name and nature of the mineral cannot be ascertained by blowpipe methods, the ability to ascertain the commercially important elements that it contains is often of the

greatest value, since it is then possible to decide whether it is worth while to procure a chemical analysis or an assay of the substance.

The following scheme has been devised as a guide for making a *complete* qualitative analysis of an unknown substance with the greatest economy of time and labor. It should not be expected that every mineral containing As, for instance, will yield every test for As mentioned in Chapter II or in the following outline, but in most cases the mineral will give one or more of the tests there given. It is poor practice to assume that a mineral contains a certain element and then test for that element, repeating the operation for other elements. A far better plan is to follow the outline rigidly and to draw conclusions from the results secured. This saves time and makes it impossible to forget to try tests.

If it is suspected that Hg is present in a substance, it should be tested only in the closed tube (see III.b.), as the vapors are very poisonous.

### OUTLINE

- A. Powder material very fine and place upon charcoal, pressing out with a knife-blade into a flat cake. Moisten with water if necessary to keep the charge from flying off the charcoal.
  - I. Test for As, Sb, Sn with As, Mo, Te, As with

S, Pb, Bi, Cd, Se, Ag with Pb, and S.  
(See I.)

2. Test for Fe. (See I.*p*.)

Separate the residue from the above tests into two portions and save one of these for a later test. On the portion still remaining on the charcoal make:

3. Test for Zn and Sn. (See I.*e*. and I.*g*.)

4. Test for Cu on residue from A.3. (See VII.*a*.)

5. Test for Al, Mg, Zn, Sb, and Zn silicate on residue from A.4. (See VIII.)

(This test can be made only upon light colored, infusible material, and need not be tried if Zn has already been found.)

B. If A.4. gave no Cu flame (if Cu is present it is useless to make the following tests) make borax and salt of phosphorus bead tests for the elements named below, using the residue saved from A.2.

1. Test for Fe, Mo, Ti, W, U, V, Cr, Cu, Co, Mn, and Ni. (See V. and VI.)

C. In case A.1. gave a result that might be interpreted as indicating either Pb or Bi, use the bismuth flux test to distinguish them.

1. Test for Bi on some of the original material, using bismuth flux. (See I.*j*.)

D. If A.4. gave no Cu flame (if Cu is present it is useless to make the following tests), hold a piece of the original material as large as a tooth-



pick or match in the platinum forceps and make the flame tests as described under VII., Second Method.

1. Test for Sr, Ca, Na, Ba, and Pb carbonates. (See VII., Second Method.)

If no satisfactory results are obtained from D.1., make the flame tests as described under VII., Third Method.

2. Test for Li, Sr, Ca, Na, Ba, P, B, Pb, Sb, and K. (See VII., Third Method.)

If no satisfactory results are obtained from D.2., make the flame tests as described under VII., Fourth Method.

3. Test for Li, Sr, Ca, Na, Ba, P, B, Pb, Sb, and K. (See VII., Fourth Method.)

E. On some of the original material, powdered, make the closed tube tests without flux.

1. Test for  $H_2O$ , Hg, Te, Cd, As, Sb, S, As with S, Sb with S, Hg with S, and Se. (See III.a. to l.)

On some of the original material, powdered, make the closed tube tests with flux, provided E.1. has not yielded determinative results.

2. Test for  $H_2O$ , Hg, Te, Cd, As, and Sb. (See III.m. to r.)

On some of the original material, powdered, make the closed tube test with acid potassium sulphate.

## 3. Test for F. (See III.s.)

F. On some of the original material, powdered, make the open tube tests.

1. Test for  $H_2O$ , S, As, Sb, Sb with S, Pb with S, Te, Bi with S, Mo, As with S, and Se. (See IV.)

*Note.* It is always well to make tests E. and F. even when A. has given determinative results, as several of the elements determined by means of tests E. and F. may fail to show in test A. It is a good practice to corroborate results obtained by test A. by means of tests E and F.

G. On some of the original material, powdered, make the tests on charcoal with flux.

1. Test for Zn, Ag with Pb, Pb, Bi, Ag, Sn, Au, Cu, and Fe, Co, or Ni. (See II.)

On the residue from G.1., make the silver test for S, Te, or Se, provided these elements, or one of them, have not already been detected by other tests.

2. Test for S, Te, or Se. (See II.j.)

H. On some of the original material, powdered, make the tests with acids in test-tubes.

1. Test for a silicate with nitric acid. (See IX.a.)
2. Test for a carbonate with hydrochloric acid. (See IX.b.)

## CHAPTER IV

### INDEX TO ALL OF THE TESTS YIELDED BY THE VARIOUS ELEMENTS

It is the purpose of this index to furnish a complete list of all the blowpipe tests for any element discussed in the preceding pages. It will be found useful where the interest is concentrated upon one or two elements to the exclusion of all others, but should not be used in making a complete qualitative blowpipe analysis of a substance. It should not be expected, that any mineral will necessarily yield *all* of the tests for each of the constituents.

The references here given are to the page or pages on which tests for the various elements are described.

Aluminum: 40.

Antimony: 12, 21, 22, 24, 38, and 40.

Arsenic: 12, 14, 15, 20, 21, 22, 23, 24, and 25.

Barium: 36 and 38.

Bismuth: 14, 17, and 24.

Boron: 38.

Cadmium: 15 and 20.

Calcium: 36 and 37.

Chromium: 30 and 31.

Cobalt: 15, 19, 30, and 31.

Copper: 19, 30, 31, and 34.

Fluorine: 22.

Gold: 18.

Iron: 15, 19, 30, and 31.

Lead: 14, 15, 17, 24, 36, and 38.

Lithium: 37.

Magnesium: 40.

Manganese: 30 and 31.

Mercury: 20, 21, and 22.

Molybdenum: 13, 24, 30, and 31.

Nickel: 15, 19, 30, and 31.

Phosphorus: 38.

Potassium: 38.

Selenium: 15, 19, 22, and 25.

Silver: 15, 17, and 18.

Sodium: 36 and 37.

Strontium: 36 and 37.

Sulphur: 14, 15, 19, 21, 23, 24, and 25.

Tellurium: 13, 19, 20, 21, 22, and 24.

Tin: 14 and 18.

Titanium: 30 and 31.

Tungsten: 30 and 31.

Uranium: 30 and 31.

*TESTS YIELDED BY VARIOUS ELEMENTS* 49

**Zinc:** 13, 17, and 40.

**Water:** 20, 22, and 23.

**A carbonate:** 41.

**A silicate:** 40.

## CHAPTER V

### THE DETERMINATION OF MINERALS BY MEANS OF THE BLOWPIPE

WHILE the determination of the constituent elements of a mineral is the usual aim of a blowpipe analysis, it is often desirable to be able to assign the correct mineralogical name to the substance, since, when this can be done, it is frequently possible to determine its percentage composition with considerable accuracy. It is not, unfortunately, possible in many cases to determine a mineral by blowpipe tests alone; these must be considered in connection with the physical characteristics before a reliable decision as to the correct name can be safely made. There are, however, a considerable number of minerals with unique groups of constituents which may be determined by blowpipe analyses, and it is hoped that the following table will prove useful in this respect. It includes most of the important ores and some of lesser importance, as well as a number of gangue minerals, but some very important ores are omitted as well as a great number of common minerals for the reason that blowpipe tests are little or no aid in their recognition. In a large

number of cases two or more minerals on this table yield tests for identically the same elements. Such substances can be readily distinguished by their appearance or by simple physical tests. For this purpose almost any book on mineralogy will answer, but the author naturally prefers his own work, *A Pocket Handbook of Minerals*, published by John Wiley & Sons, New York, which places all the emphasis upon the physical distinctions.

In the following table the chemical formula is placed in parentheses after the name of each mineral. By applying the principles presented in Chapter VI it should be a comparatively simple matter to compute the percentage of any or all elements present in any mineral of fixed composition. The letters to the left of each name are the symbols of the elements that may be found by means of the blowpipe; in comparatively few cases do they constitute all the elements present in the mineral before which they stand, but the remainder fail to give satisfactory tests with the blowpipe.

The name of a mineral is repeated under each element for which it yields blowpipe tests. Water ( $\text{H}_2\text{O}$ ) is treated as an element.

#### **Aluminum.**

Al—Corundum ( $\text{Al}_2\text{O}_3$ )

Al, Li—Spodumene ( $\text{LiAlSi}_2\text{O}_6$ ).

Al, P,  $\text{H}_2\text{O}$ —Turquoise ( $\text{AlPO}_4 \cdot \text{Al}(\text{OH})_3 + \text{H}_2\text{O} + \text{Cu}$ ).

Al, K—Orthoclase ( $\text{KAlSi}_3\text{O}_8$ ).

Al, S,  $\text{H}_2\text{O}$ —Alunite ( $\text{K}_2\text{SO}_4 \cdot 3\text{Al}_2\text{O}_3 \cdot 3\text{SO}_3 \cdot 6\text{H}_2\text{O}$ ).

Al,  $\text{H}_2\text{O}$ —Bauxite ( $\text{Al}_2\text{O}_3 + 2\text{H}_2\text{O}$ ).

Al,  $\text{H}_2\text{O}$ —Kaolin ( $\text{Al}_2\text{Si}_2\text{O}_7 + 2\text{H}_2\text{O}$ ).

### Antimony.

Sb—Native Antimony (Sb).

Sb—Cervantite ( $\text{Sb}_2\text{O}_4$ ).

Sb, As—Allemontite ( $\text{SbAs}$ ).

Sb, Cu, S—Tetrahedrite ( $\text{Cu}_8\text{Sb}_2\text{S}_7$ ).

Sb, Pb, S—Jamesonite ( $\text{Pb}_2\text{Sb}_2\text{S}_5$ ).

Sb, Ag, S—Pyrargyrite ( $\text{Ag}_3\text{SbS}_3$ ).

Sb, Ag, S—Stephanite ( $\text{Ag}_5\text{SbS}_4$ ).

Sb, S—Stibnite ( $\text{Sb}_2\text{S}_3$ ).

### Arsenic.

As—Native Arsenic (As).

As, Sb—Allemontite ( $\text{AsSb}$ ).

As, Co—Smaltite ( $((\text{Co}, \text{Ni}) \text{As}_2)$ ).

As, Co, S—Cobaltite ( $\text{CoAsS}$ ).

As, Cu, S—Tennantite ( $\text{Cu}_8\text{As}_2\text{S}_7$ ).

As, Cu, S—Enargite ( $\text{Cu}_3\text{AsS}_4$ ).

As, Cu,  $\text{H}_2\text{O}$ —Olivenite ( $\text{Cu}_4\text{As}_2\text{O}_9 + \text{H}_2\text{O}$ ).

As, Cu,  $\text{H}_2\text{O}$ —Conichalcite ( $((\text{Cu}, \text{Ca})_4\text{As}_2\text{O}_9 + 3/2\text{H}_2\text{O})$ ).

As, Fe—Lollingite ( $\text{FeAs}_2$ ).

As, Fe, S—Arsenopyrite ( $\text{FeAsS}$ ).

As, Ni—Niccolite ( $\text{NiAs}$ ).

As, Pb—Mimetite ( $\text{PbCl}_2 \cdot 3\text{Pb}_3\text{As}_2\text{O}_8$ ).

As, Ag, S—Proustite ( $\text{Ag}_3\text{AsS}_3$ ).



As, S—Realgar ( $\text{As}_2\text{S}_2$ ).

As, S—Orpiment ( $\text{As}_2\text{S}_3$ ).

### Barium.

Ba—Witherite ( $\text{BaCO}_3$ ).

Ba, S—Barite ( $\text{BaSO}_4$ ).

### Bismuth.

Bi—Native Bismuth (Bi).

Bi—Bismite ( $\text{Bi}_2\text{O}_3$ ).

Bi, S—Bismuthinite ( $\text{Bi}_2\text{S}_3$ ).

Bi, Te—Tetradymite ( $\text{TeBi}$ ).

Bi,  $\text{H}_2\text{O}$ —Bismutite ( $\text{Bi}_2\text{CO}_5 + \text{H}_2\text{O}$ ).

### Boron.

B—Boracite ( $\text{Mg}_7\text{Cl}_2\text{B}_{16}\text{O}_{30}$ ).

B, Na,  $\text{H}_2\text{O}$ —Borax ( $\text{Na}_2\text{B}_4\text{O}_7 + 10\text{H}_2\text{O}$ ).

B,  $\text{H}_2\text{O}$ —Colemanite ( $\text{Ca}_2\text{B}_6\text{O}_{11} + 5\text{H}_2\text{O}$ ).

### Cadmium.

Cd, S—Greenockite ( $\text{CdS}$ ).

### Calcium.

Ca—Calcite ( $\text{CaCO}_3$ ).

Ca, F—Fluorite ( $\text{CaF}_2$ ).

Ca, Mg—Dolomite ( $(\text{Ca}, \text{Mg}) \text{CO}_3$ ).

Ca, P—Apatite ( $\text{Ca} (\text{Cl}, \text{F})_{2.3} \text{Ca}_3\text{P}_2\text{O}_8$ ).

Ca, S—Anhydrite ( $\text{CaSO}_4$ ).

Ca, S,  $\text{H}_2\text{O}$ —Gypsum ( $\text{CaSO}_4 + 2\text{H}_2\text{O}$ ).

### Chromium.

Cr, Fe—Chromite ( $\text{FeCr}_2\text{O}_4$ ).

Cr, Pb—Crocoite ( $\text{PbCrO}_4$ ).

**Cobalt.**

Co, As—Smaltite ((Co, Ni) As<sub>2</sub>).

Co, As, S—Cobaltite (CoAsS).

**Copper**

Cu—Native Copper (Cu).

Cu—Cuprite (Cu<sub>2</sub>O).

Cu—Tenorite (CuO).

Cu—Atacamite (CuCl<sub>2</sub>·3Cu(OH)<sub>2</sub>).

Cu, Sb, S—Tetrahedrite (Cu<sub>8</sub>Sb<sub>2</sub>S<sub>7</sub>).

Cu, As, S—Tennantite (Cu<sub>8</sub>As<sub>2</sub>S<sub>7</sub>).

Cu, As, S—Enargite (Cu<sub>3</sub>AsS<sub>4</sub>).

Cu, As, H<sub>2</sub>O—Olivenite (Cu<sub>4</sub>As<sub>2</sub>O<sub>9</sub> + H<sub>2</sub>O).

Cu, As, H<sub>2</sub>O—Conichalcite ((Cu, Ca)<sub>4</sub>As<sub>2</sub>O<sub>9</sub> +  
3/2H<sub>2</sub>O).

Cu, Fe, S—Bornite (Cu<sub>5</sub>FeS<sub>4</sub>).

Cu, Fe, S—Chalcopyrite (CuFeS<sub>2</sub>).

Cu, S—Chalcocite (Cu<sub>2</sub>S).

Cu, S—Covellite (CuS).

Cu, S, H<sub>2</sub>O—Chalcanthite (CuSO<sub>4</sub> + 5H<sub>2</sub>O).

Cu, H<sub>2</sub>O—Malachite (Cu<sub>2</sub>CO<sub>4</sub> + H<sub>2</sub>O).

Cu, H<sub>2</sub>O—Azurite (Cu<sub>3</sub>C<sub>2</sub>O<sub>7</sub> + H<sub>2</sub>O).

Cu, H<sub>2</sub>O—Chrysocolla (CuSiO<sub>3</sub> + 2H<sub>2</sub>O).

**Fluorine.**

F, Ca—Fluorite (CaF<sub>2</sub>).

F, Na—Cryolite (Na<sub>3</sub>AlF<sub>6</sub>).

**Gold.**

Au—Native Gold (Au).

Au, Te—Calaverite (AuTe<sub>2</sub>).

**Iron.**

- Fe—Hematite ( $\text{Fe}_2\text{O}_3$ ).
- Fe—Magnetite ( $\text{Fe}_3\text{O}_4$ ).
- Fe—Siderite ( $\text{FeCO}_3$ ).
- Fe, As—Lollingite ( $\text{FeAs}_2$ ).
- Fe, As, S—Arsenopyrite ( $\text{FeAsS}$ ).
- Fe, Cr—Chromite ( $\text{FeCr}_2\text{O}_4$ ).
- Fe, Mn, Zn—Franklinite ( $(\text{Fe}, \text{Zn}, \text{Mn})_3\text{O}_4$ ).
- Fe, P,  $\text{H}_2\text{O}$ —Vivianite ( $\text{Fe}_3\text{P}_2\text{O}_8 + 8\text{H}_2\text{O}$ ).
- Fe, S—Pyrrhotite ( $\text{Fe}_n\text{S}_{n+1}$ ).
- Fe, S—Pyrite ( $\text{FeS}_2$ ).
- Fe, Ti—Ilmenite ( $\text{FeTiO}_3$ ).
- Fe,  $\text{H}_2\text{O}$ —Limonite ( $2\text{Fe}_2\text{O}_3 + 3\text{H}_2\text{O}$ ).

**Lead.**

- Pb—Cerussite ( $\text{PbCO}_3$ ).
- Pb, Sb, S—Jamesonite ( $\text{Pb}_2\text{Sb}_2\text{S}_5$ ).
- Pb, As—Mimetite ( $\text{PbCl}_{2.3}\text{Pb}_3\text{As}_2\text{O}_8$ ).
- Pb, Cr—Crocoite ( $\text{PbCrO}_4$ ).
- Pb, Mo—Wulfenite ( $\text{PbMoO}_4$ ).
- Pb, P—Pyromorphite ( $\text{PbCl}_{2.3}\text{Pb}_3\text{P}_2\text{O}_8$ ).
- Pb, S—Galenite ( $\text{PbS}$ ).
- Pb, S—Anglesite ( $\text{PbSO}_4$ ).
- Pb, V—Vanadinite ( $\text{PbCl}_{2.3}\text{Pb}_3\text{V}_2\text{O}_8$ ).
- Pb, V, etc.—Uraninite (?).

**Lithium.**

- Li, Al—Spodumene ( $\text{LiAlSi}_2\text{O}_6$ ).

**Magnesium**

- Mg—Magnesite ( $\text{MgCO}_3$ ).

Mg, Ca—Dolomite ( $(\text{Mg}, \text{Ca})\text{CO}_3$ ).

Mg,  $\text{H}_2\text{O}$ —Talc ( $\text{Mg}_3\text{Si}_4\text{O}_{11} + \text{H}_2\text{O}$ ).

### Manganese.

Mn—Pyrolusite ( $\text{MnO}_2$ ).

Mn—Rhodochrosite ( $\text{MnCO}_3$ ).

Mn—Rhodonite ( $\text{MnSiO}_3$ ).

Mn, Fe, Zn—Franklinite ( $(\text{Mn}, \text{Fe}, \text{Zn})_3\text{O}_4$ ).

Mn, S—Alabandite ( $\text{MnS}$ ).

Mn,  $\text{H}_2\text{O}$ —Manganite ( $\text{Mn}_2\text{O}_3 + \text{H}_2\text{O}$ ).

Mn,  $\text{H}_2\text{O}$ —Psilomelane ( $\text{MnO}_2 + 2\text{H}_2\text{O}$ ).

### Mercury.

Hg—Native Mercury (Hg).

Hg, S—Cinnabar ( $\text{HgS}$ ).

### Molybdenum.

Mo—Molybdite ( $\text{MoO}_3$ ).

Mo, Pb—Wulfenite ( $\text{PbMoO}_4$ ).

Mo, S—Molybdenite ( $\text{MoS}_2$ ).

### Nickel.

Ni, As—Niccolite ( $\text{NiAs}$ ).

Ni, S—Millerite ( $\text{NiS}$ ).

Ni,  $\text{H}_2\text{O}$ —Garnierite ( $\text{H}_2(\text{Ni}, \text{Mg})\text{SiO}_4 + \text{H}_2\text{O}$ ).

### Phosphorus.

P, Al,  $\text{H}_2\text{O}$ —Turquoise ( $\text{AlPO}_4 \cdot \text{Al}(\text{OH})_3 + \text{H}_2\text{O} + \text{Cu}$ ).

P, Ca—Apatite ( $\text{Ca}(\text{Cl}, \text{F})_{2.3}\text{Ca}_3\text{P}_2\text{O}_8$ ).

P, Fe,  $\text{H}_2\text{O}$ —Vivianite ( $\text{Fe}_3\text{P}_2\text{O}_8 + 8\text{H}_2\text{O}$ ).

P, Pb—Pyromorphite ( $\text{PbCl}_{2.3}\text{Pb}_3\text{P}_2\text{O}_8$ ).

**Potassium.**

K—Sylvite (KCl).

K, Al—Orthoclase ( $\text{KAlSi}_3\text{O}_8$ ).

**Selenium.**

Se, Pb—Clausthalite ( $\text{PbSe}$ ).

**Silver.**

Ag—Native Silver (Ag).

Ag—Cerargyrite ( $\text{AgCl}$ ).

Ag, Sb, S—Pyrargyrite ( $\text{Ag}_3\text{SbS}_3$ ).

Ag, Sb, S—Stephanite ( $\text{Ag}_5\text{SbS}_4$ ).

Ag, As, S—Proustite ( $\text{Ag}_3\text{AsS}_3$ ).

Ag, Te—Petzite ( $(\text{Ag}, \text{Au})_2\text{Te}$ ).

Ag, Te—Sylvanite ( $(\text{Ag}, \text{Au})\text{Te}_2$ ).

Ag, S—Argentite ( $\text{Ag}_2\text{S}$ ).

Ag, Te—Hessite ( $\text{Ag}_2\text{Te}$ ).

**Sodium**

Na—Halite ( $\text{NaCl}$ ).

Na, B,  $\text{H}_2\text{O}$ —Borax ( $\text{Na}_2\text{B}_4\text{O}_7 + 10\text{H}_2\text{O}$ ).

Na, F—Cryolite ( $\text{Na}_3\text{AlF}_6$ ).

Na, S—Thenardite ( $\text{Na}_2\text{SO}_4$ ).

Na,  $\text{H}_2\text{O}$ —Natron ( $\text{Na}_2\text{CO}_3 + 10\text{H}_2\text{O}$ ).

Na,  $\text{H}_2\text{O}$ —Trona ( $\text{Na}_2\text{CO}_3 \cdot \text{HNaCO}_3 + 2\text{H}_2\text{O}$ ).

**Strontium**

Sr—Strontianite ( $\text{SrCO}_3$ ).

Sr, S—Celestite ( $\text{SrSO}_4$ ).

**Sulphur.**

S—Native Sulphur (S).

S, Al, H<sub>2</sub>O—Alunite ( $K_2SO_4 \cdot 3Al_2O_3 \cdot 3SO_3 \cdot 6H_2O$ ).

S, Sb—Stibnite (Sb<sub>2</sub>S<sub>3</sub>).

S, Sb, Cu—Tetrahedrite (Cu<sub>8</sub>Sb<sub>2</sub>S<sub>7</sub>).

S, Sb, Pb—Jamesonite (Pb<sub>2</sub>Sb<sub>2</sub>S<sub>5</sub>).

S, Sb, Ag—Pyrargyrite (Ag<sub>3</sub>SbS<sub>3</sub>).

S, As—Realgar (As<sub>2</sub>S<sub>2</sub>).

S, As—Orpiment (As<sub>2</sub>S<sub>3</sub>).

S, As, Cu—Tennantite (Cu<sub>8</sub>As<sub>2</sub>S<sub>7</sub>).

S, As, Cu—Enargite (Cu<sub>3</sub>AsS<sub>4</sub>).

S, As, Fe—Arsenopyrite (FeAsS).

S, As, Ag—Proustite (Ag<sub>3</sub>AsS<sub>3</sub>).

S, Ba—Barite (BaSO<sub>4</sub>).

S, Bi—Bismuthinite (Bi<sub>2</sub>S<sub>3</sub>).

S, Cd—Greenockite (CdS).

S, Ca—Anhydrite (CaSO<sub>4</sub>).

S, Ca, H<sub>2</sub>O—Gypsum (CaSO<sub>4</sub> + 2H<sub>2</sub>O).

S, Cu—Chalcocite (Cu<sub>2</sub>S).

S, Cu—Covellite (CuS).

S, Cu, Fe—Bornite (Cu<sub>5</sub>FeS<sub>4</sub>).

S, Cu, Fe—Chalcopyrite (CuFeS<sub>2</sub>).

S, Cu, H<sub>2</sub>O—Chalcanthite (CuSO<sub>4</sub> + 5H<sub>2</sub>O).

S, Fe—Pyrrhotite (Fe<sub>n</sub>S<sub>n+1</sub>).

S, Fe—Pyrite (FeS<sub>2</sub>).

S, Pb—Galenite (PbS).

S, Pb—Anglesite (PbSO<sub>4</sub>).

S, Mn—Alabandite (MnS).

S, Mo—Molybdenite (MoS<sub>2</sub>).

- S, Ni—Millerite ( $\text{NiS}$ ).
- S, Ag—Argentite ( $\text{Ag}_2\text{S}$ ).
- S, Na—Thenardite ( $\text{Na}_2\text{SO}_4$ ).
- S, Sr—Celestite ( $\text{SrSO}_4$ ).
- S, Zn—Sphalerite ( $\text{ZnS}$ ).

**Tellurium.**

- Te—Native Tellurium ( $\text{Te}$ ).
- Te, Bi—Tetradymite ( $\text{BiTe}$ ).
- Te, Au—Calaverite ( $\text{AuTe}_2$ ).
- Te, Ag—Petzite ( $(\text{Au}, \text{Ag})_2\text{Te}$ ).
- Te, Ag—Hessite ( $\text{Ag}_2\text{Te}$ ).
- Te, Ag—Sylvanite ( $(\text{Au}, \text{Ag})\text{Te}_2$ ).

**Tin.**

- Sn—Cassiterite ( $\text{SnO}_2$ ).

**Titanium.**

- Ti—Rutile ( $\text{TiO}_2$ ).
- Ti—Titanite ( $\text{CaTiSiO}_5$ ).
- Ti, Fe—Ilmenite ( $\text{FeTiO}_3$ ).

**Tungsten.**

- W—Scheelite ( $\text{CaWO}_4$ ).

**Uranium.**

- U, Pb, etc.—Uraninite (?).

**Vanadium.**

- V, Pb—Vanadinite ( $\text{PbCl}_{2.3}\text{Pb}_3\text{V}_2\text{O}_8$ ).

**Zinc.**

- Zn—Zincite ( $\text{ZnO}$ ).
- Zn—Smithsonite ( $\text{ZnCO}_3$ ).

Zn—Willemite ( $\text{Zn}_2\text{SiO}_4$ ).

Zn, Fe, Mn—Franklinite ( $(\text{Zn}, \text{Fe}, \text{Mn})_3\text{O}_4$ ).

Zn, S—Sphalerite ( $\text{ZnS}$ ).

Zn,  $\text{H}_2\text{O}$ —Hydrozincite ( $3\text{ZnCO}_3 + 2\text{H}_2\text{O}$ ).

Zn,  $\text{H}_2\text{O}$ —Calamine ( $\text{Zn}_2\text{SiO}_4 + \text{H}_2\text{O}$ ).

### Water.

$\text{H}_2\text{O}$ , Al—Bauxite ( $\text{Al}_2\text{O}_3 + 2\text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , Al—Kaolin ( $\text{Al}_2\text{Si}_2\text{O}_7 + 2\text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , Al, P—Turquoise ( $\text{AlPO}_4 \cdot \text{Al}(\text{OH})_3 + \text{H}_2\text{O} + \text{Cu}$ ).

$\text{H}_2\text{O}$ , Al, S—Alunite ( $\text{K}_2\text{SO}_4 \cdot 3\text{Al}_2\text{O}_3 \cdot 3\text{SO}_3 \cdot 6\text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , As, Cu—Olivenite ( $\text{Cu}_4\text{As}_2\text{O}_9 + \text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , As, Cu—Conichalcite ( $(\text{Cu}, \text{Ca})_4\text{As}_2\text{O}_9 + 3/2\text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , Bi—Bismutite ( $\text{Bi}_2\text{CO}_5 + \text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , B—Colemanite ( $\text{Ca}_2\text{B}_6\text{O}_{11} + 5\text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , B, Na—Borax ( $\text{Na}_2\text{B}_4\text{O}_7 + 10\text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , Ca, S—Gypsum ( $\text{CaSO}_4 + 2\text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , Cu—Malachite ( $\text{Cu}_2\text{CO}_4 + \text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , Cu—Azurite ( $\text{Cu}_3\text{C}_2\text{O}_7 + \text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , Cu—Crysocolla ( $\text{CuSiO}_3 + 2\text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , Fe—Limonite ( $2\text{Fe}_2\text{O}_3 + 3\text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , Fe, P—Vivianite ( $\text{Fe}_3\text{P}_2\text{O}_8 + 8\text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , Mg—Talc ( $\text{Mg}_3\text{Si}_4\text{O}_{11} + \text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , Mn—Manganite ( $\text{Mn}_2\text{O}_3 + \text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , Mn—Psilomelane ( $\text{MnO}_2 + 2\text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , Ni—Garnierite ( $\text{H}_2(\text{Ni}, \text{Mg})\text{SiO}_4 + \text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , Na—Natron ( $\text{Na}_2\text{CO}_3 + 10\text{H}_2\text{O}$ ).

$\text{H}_2\text{O}$ , Na—Trona ( $\text{Na}_2\text{CO}_3 \cdot \text{HNaCO}_3 + 2\text{H}_2\text{O}$ ).



H<sub>2</sub>O, Zn—Hydrozincite ( $3\text{ZnCO}_3 + 2\text{H}_2\text{O}$ ).

H<sub>2</sub>O, Zn—Calamine ( $\text{Zn}_2\text{SiO}_4 + \text{H}_2\text{O}$ ).

### Silicates.

The two mentioned below are the only ones in the above list which will give the test for a silicate described previously.

Willemite ( $\text{Zn}_2\text{SiO}_4$ ).

Calamine ( $\text{Zn}_2\text{SiO}_4 + \text{H}_2\text{O}$ ).

### Carbonates. .

Ba—Witherite ( $\text{BaCO}_3$ ).

Bi—Bismutite ( $\text{Bi}_2\text{CO}_5 + \text{H}_2\text{O}$ ).

Ca—Calcite ( $\text{CaCO}_3$ ).

Ca, Mg—Dolomite ( $(\text{Ca}, \text{Mg})\text{CO}_3$ ).

Cu, H<sub>2</sub>O—Malachite ( $\text{Cu}_2\text{CO}_4 + \text{H}_2\text{O}$ ).

Cu, H<sub>2</sub>O—Azurite ( $\text{Cu}_3\text{C}_2\text{O}_7 + \text{H}_2\text{O}$ ).

Fe—Siderite ( $\text{FeCO}_3$ ).

Pb—Cerussite ( $\text{PbCO}_3$ ).

Mg—Magnesite ( $\text{MgCO}_3$ ).

Mn—Rhodochrosite ( $\text{MnCO}_3$ ).

Na, H<sub>2</sub>O—Natron ( $\text{Na}_2\text{CO}_3 + 10\text{H}_2\text{O}$ ).

Na, H<sub>2</sub>O—Trona ( $\text{Na}_2\text{CO}_3 \cdot \text{HNaCO}_3 + 2\text{H}_2\text{O}$ ).

Sr—Strontianite ( $\text{SrCO}_3$ ).

Zn—Smithsonite ( $\text{ZnCO}_3$ ).

Zn, H<sub>2</sub>O—Hydrozincite ( $3\text{ZnCO}_3 + 2\text{H}_2\text{O}$ ).

## CHAPTER VI

### THE ELEMENTARY PRINCIPLES OF CHEMISTRY

#### THE USE AND INTERPRETATION OF CHEMICAL SYMBOLS

**Elements.** Every body in nature is composed of one of more constituent substances called elements. Sometimes, as in the case of the metals gold, silver, and copper, there is only one substance; it is itself an element. In other cases there are two or more elemental constituents present in the body, which by proper manipulation may be broken up or resolved into its elements.

An element, is then, something that has resisted all attempts to subdivide it into other substances. It follows, necessarily, that an element cannot be formed by a union of other substances.

Each element differs more or less from all others in appearance, properties, and uses. Some are gases, some are opaque and reflect light from the surface—are metals, and some are transparent or translucent—are non-metals. The distinction between metals and non-metals is, however, not sharply marked, since there are elements with inter-

mediate properties. A full list of all known elements is given in the table at the end of this chapter.

It has happened occasionally that a substance supposed to be an element has been found to be composed of two or more elements, and this will probably occur in the future, but chemists feel practically certain of the elementary condition of all the commoner elements. They know now that the Alchemists' search for a method of making gold was foredoomed to failure.

**Chemical Compounds.** Elements have the property of uniting under certain conditions to form new substances, differing in nature from any of the constituent elements. The results of such unions are not merely mechanical mixtures of the elements in which each component can be identified under the high-power microscope, but are homogeneous substances of definite properties, which will often fail to respond to tests yielded by their constituent elements. Such combinations of two or more elements are called chemical compounds. Thus, the common chemical compound water is composed of one gas, hydrogen, which burns in the air, and another, oxygen, which is essential for respiration, properties quite foreign to water.

Most natural bodies are either chemical compounds or mixtures of them. Other peculiarities possessed by them will be mentioned later.

**Alloys.** Alloys are rather indefinite compounds

of metals whose natures are not thoroughly understood.

**Atoms.** Atoms are the smallest particles into which it is believed an element may be divided and still retain all its distinguishing properties. Although not infinitely small, they are far too minute to be seen with the microscope, yet there are abundant more or less indirect proofs of the correctness of the atomic theory. That atoms are themselves subdivisible is now admitted, but these lesser particles reveal the characteristic properties of entirely different elements from those which they formed before disintegration, and are produced only under very unusual conditions, probably never, or very rarely, duplicated in chemical operations.

According to the atomic theory, the atoms of any element have the same weight and size and are identically alike, while the atoms of different elements have different weights and sizes, and further differ to the same extent as do the elements themselves.

**Molecules.** Molecules are the smallest particles into which it is believed a chemical *compound* may be divided and still remain the same chemical compound. They must consist, evidently, of at least two, and often several, atoms. The same word (molecule) is also applied to the smallest volumes of a gas, even though it be an element instead of a compound, since it appears certain that the smallest

particles of gases always consist of at least two atoms.

With certain modifications that it is not necessary to discuss, it may be stated that the number of atoms present in a molecule of a given chemical compound is always the same, and that the different atoms forming a molecule of a certain chemical compound are always present in a fixed proportion. Thus, a molecule of water always contains two atoms of hydrogen and one atom of oxygen.

**Symbols.** For convenience, the elements are represented by the initial letter, either alone or with an added letter, of their Latin or Greek names, which are in many cases very similar to their English names. These letters are called the symbols of the elements.

**Formulae.** The formula of a chemical compound is written by placing the symbols of its component elements in a line, and, if more than one atom of any of these is present in the molecule of the compound, the number of such atoms is indicated by subscripts written after the symbols of the elements thus affected. Thus, the formula of water is  $\text{H}_2\text{O}$ , indicating that the molecule of water contains two atoms of H combined with one atom of O. This formula is read h-two-o.

It is sometimes possible to group the atoms in the formula of a complex substance in such a fashion as to form two or more groups of molecules, indicat-

ing that the substance may be formed not only by a union of atoms but also by a combination of molecules. Such formulæ may be written with a period separating the constituent molecules. Thus,  $\text{CaCO}_3$  (read c-a-c-o-three) is the symbol of calcite, of which marble is a variety, and this formula may be written  $\text{CaO.CO}_2$ , indicating that the material is formed by the union of one molecule of lime ( $\text{CaO}$ ) and one of carbonic acid gas ( $\text{CO}_2$ ). When it is possible to break up a formula into molecules in this way, it is often found that more than one of a certain constituent molecule is present in substance. Thus, the ordinary formula of orthoclase feldspar is  $\text{KAlSi}_3\text{O}_8$ , but, after multiplying each atom by two, this is found to consist of one molecule of potassium oxide ( $\text{K}_2\text{O}$ ), one of alumina ( $\text{Al}_2\text{O}_3$ ), and six of silica ( $\text{SiO}_2$ ), and may therefore be written  $\text{K}_2\text{O.Al}_2\text{O}_3.6\text{SiO}_2$ . The order in which the different molecules are written is of no great importance; the above formula might with equal correctness be written  $6\text{SiO}_2.\text{K}_2\text{O.Al}_2\text{O}_3$ , although this is not the customary order. It should be noticed that a figure prefixed to a molecule, as in the case of the 6 in the above formula, applies only to the *molecule* to which it is prefixed.

Sometimes formulæ like the following (the formula of emerald) are used:  $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$ . This is read b-e-three-a-l-two-parenthesis-s-i-o-three-taken-six-times. Both the Si and the O in the parenthesis are

affected by the subscript 6 and might be written  $\text{Si}_6\text{O}_{18}$ , but it is sometimes desirable to group elements in parentheses in this way. Groups like this are not molecules since they do not occur as known chemical compounds.

A different use of the parenthesis is seen in the case of those compounds in which the relative proportions of certain compounds are apt to vary—apparently a modification or violation of a previously expressed law. Thus, a common constituent of limestone is a mineral called dolomite, whose formula is  $(\text{Mg}, \text{Ca})\text{CO}_3$ . Here the comma between the Mg and Ca indicates that the relative proportion of Mg and Ca is not fixed; there may be a nearly or quite equal number of atoms of both present, or either may predominate to a small or great extent over the other. In an instance like this the element first written in the parenthesis is apt to be the more plentiful. Sometimes it is more convenient (as when the horizontal space is limited) to write the variable elements in such formulæ in a vertical column without using the comma, in this manner:  $\begin{pmatrix} \text{Mg} \\ \text{Ca} \end{pmatrix} \text{CO}_3$ .

**Atomic weights.** The atomic weight of an element is the relative weight of an atom of the element compared with the weight of an atom of H, which is taken as unity, it being the lightest known element. Thus, an atom of Fe is fifty-six

times as heavy as an atom of H, so the atomic weight of Fe is 56. A presentation of the methods by which the atomic weights of the various elements are determined is not necessary, but these atomic weights have a practical use which is important. This may be illustrated as follows: Since pure water is composed entirely of molecules having the formula  $H_2O$ , if we know the relative weights of the H and O atoms, it should be a simple matter to calculate the proportions by weight of H and O in the molecule, and thus to determine the proportion by weight of these elements in any amount of the substance. There being two atoms of H present in the molecule, each of which weighs one unit (atomic weight of H is 1), and one atom of O, which weighs sixteen units (atomic weight of O is 16), the whole molecule must weigh  $2 + 16 = 18$  units. It is plain that the H must constitute  $\frac{2}{18}$ , or  $\frac{1}{9}$ , and the O form  $\frac{16}{18}$ , or  $\frac{8}{9}$  of the whole molecule. It follows that pure water in any amount is  $\frac{1}{9}$  H and  $\frac{8}{9}$  O.

In this way it is always possible to calculate the relative proportions of the different elements in a substance whose formula is known, provided no elements involved occur in variable quantities, indicated by placing them, separated by commas, in parentheses, or in vertical columns in parentheses, as previously explained. The atomic weights of



all the elements are given in the table at the end of this chapter.

Suppose, for illustration, it be required to find how many pounds of each of the component elements there are in 100 pounds of pure marble, with the formula  $\text{CaCO}_3$ . Let the abbreviation A.W. mean atomic weight, then—

A.W. Ca = 40. Total weight of the one Ca atom = 40 H units.

A.W. C = 12. Total weight of the one C atom = 12 H units.

A.W. O = 16. Total weight of the three O atoms = 48 ( $3 \times 16$ ) H units.

Total weight of the molecule = 100 H units.

Ca present is  $\frac{40}{100}$  of whole = 40% = 40 pounds.

C present is  $\frac{12}{100}$  of whole = 12% = 12 pounds.

O present is  $\frac{48}{100}$  of whole = 48% = 48 pounds.

As a still more complex case, let it be required to ascertain the amount of Zn and  $\text{H}_2\text{O}$  in 100 pounds of hydrozincite, with the formula  $3\text{ZnCO}_3 + 2\text{H}_2\text{O}$ .

A.W. Zn = 65.4. Number of atoms of Zn = 3.

Weight of three Zn atoms ( $3 \times 65.4$ ) = 196.2.

A.W. C = 12. Number of atoms of C = 3. Weight of three C atoms ( $3 \times 12$ ) = 36.

A.W. O = 16. Number of atoms of O = 11. Weight of eleven O atoms ( $11 \times 16$ ) = 176.

A.W. H = 1. Number of atoms of H = 4. Weight of four H atoms ( $4 \times 1$ ) = 4.

Weight of molecule (in H units) = 412.2.

Zn present is  $\frac{196.2}{412.2}$  of whole = 47.6% = 47.6 pounds.

H<sub>2</sub>O present is  $\frac{36}{412.2}$  of whole = 8.7% = 8.7 pounds.

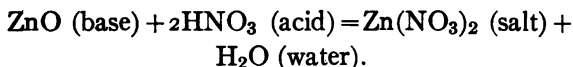
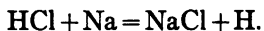
**Molecular Weights.** The molecular weight of a molecule or chemical compound is the sum of the atomic weights of the elements forming the molecule or compound, taking the atomic weight of each element as many times as there are atoms of that element present.

**Acids.** Acids are substances that impart a red coloration to blue litmus paper. Two kinds are recognized: the halogen acids, compounds of H and one of the so-called halogen elements, Cl, F, Br, and I, and the oxygen acids, compounds of O and H with some other element.

Sometimes several acids are formed by using different proportions of the same elements. The termination "ous" is then used in the name of the one with a relatively low percentage of O, and the termination "ic" in the name of the one with a relatively high percentage of that element. Thus, H<sub>2</sub>SO<sub>3</sub> is sulphurous, and H<sub>2</sub>SO<sub>4</sub> is sulphuric acid.

Among the other commoner inorganic acids are the following: Hydrochloric (HCl), hydrofluoric (HF), silicic (H<sub>4</sub>SiO<sub>4</sub>), carbonic (H<sub>2</sub>CO<sub>3</sub>), nitric (HNO<sub>3</sub>), boric or boracic (H<sub>3</sub>BO<sub>3</sub>), and phosphoric (H<sub>3</sub>PO<sub>4</sub>).

**Bases, Salts, and Chemical Equations.** Bases are such substances as impart a blue color to red litmus paper, or which are capable of replacing all or part of the H in an acid and forming a substance called a salt. Bases are always metals, combinations of metal and O, or the latter with the addition of H. Thus, when Na (a base) is added to HCl (an acid), NaCl (a salt) is formed and H is liberated. Such changes as this, called chemical reactions, may be expressed in the form of an equation, thus:



The opposite sides of chemical equations must always contain the same number of atoms of each element involved. When this is true, they are said to balance.

From the above discussion, it is plain that a salt may be defined as a compound that is formed by the reaction of an acid and a base; all or part of the H in the acid is replaced by one or more metals.

If a salt is formed from an acid with the "ous" termination, its name terminates in "ite." Thus,  $\text{Na}_2\text{SO}_3$  (formed from sulphurous acid) is known as sodium *sulphite* or *sulphite* of sodium. When the salt is formed from an acid with the "ic" termination, its name terminates in "ate." Thus, the  $\text{Zn(NO}_3)_2$  obtained in the reaction recently equated is called zinc *nitrate* or *nitrate* of zinc.

In cases where lack of knowledge makes it impossible to decide whether an "ic" or an "ous" acid was involved in the formation of a salt, it is usually safe to use the "ate"—the commoner—termination, calling the salts sulphates, carbonates, phosphates, etc.

**Additional Nomenclature.** When an element is combined with a non-metal, the resulting compound is named by adding the termination "ide" to the root of the name of the non-metal. The following list will illustrate this usage:  $\text{FeAs}_2$  is iron *arsenide* or *arsenide* of iron,  $\text{AgCl}_2$  is *chloride* of silver,  $\text{AuTe}_2$  is *telluride* of gold, and  $\text{Fe}_2\text{O}_3$  is *oxide* of iron.

Sometimes compounds of this type are formed in which more than one element combines with the non-metal, or one element may combine with two different non-metals, as in the following instances:  $\text{CuFeS}_2$  is copper-iron sulphide, and  $\text{Co}_2\text{As}_2\text{S}_2$  ( $\text{CoS}_2.\text{CoAs}_2$ ) is cobalt *arsenide* and sulphide. Care should be taken not to confuse the "ite" and "ide" terminations.

# ELEMENTARY PRINCIPLES OF CHEMISTRY 73

## TABLE OF ELEMENTS WITH THEIR SYMBOLS AND ATOMIC WEIGHTS

Name.	Sym- bol.	At. Wts.	Name.	Sym- bol.	At. Wts.
Aluminum.....	Al	27.1	Neodymium.....	Nd	143.6
Antimony.....	Sb	120.2	Neon.....	Ne	20
Argon.....	A	39.9	Nickel.....	Ni	58.7
Arsenic.....	As	75	Nitrogen.....	N	14.04
Barium.....	Ba	137.4	Osmium.....	Os	191
Beryllium.....	Be	9.1	Oxygen.....	O	16
Bismuth.....	Bi	208.5	Palladium.....	Pd	106.5
Boron.....	B	11	Phosphorus.....	P	31
Bromine.....	Br	79.96	Platinum.....	Pt	194.8
Cadmium.....	Cd	112.4	Potassium.....	K	39.15
Caesium.....	Cs	132.9	Praseodymium.....	Pr	140.5
Calcium.....	Ca	40.1	Radium.....	Ra	225
Carbon.....	C	12	Rhodium.....	Rh	103
Cerium.....	Ce	140.25	Rubidium.....	Rb	85.4
Chlorine.....	Cl	35.45	Ruthenium.....	Ru	101.7
Chromium.....	Cr	52.1	Samarium.....	Sm	150
Cobalt.....	Co	59	Scandium.....	Sc	44.1
Columbium.....	Cb	94	Selenium.....	Se	79.2
Copper.....	Cu	63.6	Silicon.....	Si	28.4
Erbium.....	Er	166	Silver.....	Ag	107.93
Fluorine.....	F	19	Sodium.....	Na	23.05
Gadolinium.....	Gd	156	Strontium.....	Sr	87.6
Gallium.....	Ga	70	Sulphur.....	S	32.06
Germanium.....	Ge	72.5	Tantalum.....	Ta	183
Gold.....	Au	197.2	Tellurium.....	Te	127.6
Helium.....	He	4	Terbium.....	Tb	160
Hydrogen.....	H	1.008	Thallium.....	Tl	204.1
Indium.....	In	114	Thorium.....	Th	232.5
Iodine.....	I	126.85	Thulium.....	Tm	171
Iridium.....	Ir	193	Tin.....	Sn	119
Iron.....	Fe	55.9	Titanium.....	Ti	48.1
Krypton.....	Kr	81.8	Tungsten.....	W	184
Lanthanum.....	La	138.9	Uranium.....	U	238.5
Lead.....	Pb	206.9	Vanadium.....	V	51.2
Lithium.....	Li	7.03	Xenon.....	Xe	128
Magnesium.....	Mg	24.36	Ytterbium.....	Yb	173
Manganese.....	Mn	55	Yttrium.....	Yt	89
Mercury.....	Hg	200	Zinc.....	Zn	65.4
Molybdenum.....	Mo	96	Zirconium.....	Zr	90.6



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# A Manual of Geometrical Crystallography

TREATING SOLELY OF THOSE PORTIONS  
OF THE SUBJECT USEFUL IN THE  
IDENTIFICATION OF MINERALS

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## PREFACE

CRYSTALLOGRAPHY may be studied with two distinct purposes in view. The end usually sought is the ability to describe crystals with such detailed accuracy that minor variations between them and other crystals may be detected and shown graphically or embodied in mathematical expressions. This aspect of the subject belongs unquestionably in the realm of pure science. It involves the accurate measurement of angles with delicate instruments requiring careful manipulation, and the results secured are not sought with any idea that they may have practical value.

Quite different is the other purpose to which reference has been made, since it is the attainment of the ability to recognize crystal forms and especially systems almost instantly with the use of few if any instruments, and those who seek this knowledge do so wholly because they expect to use it as a tool for identifying minerals.

It is of the phase of the subject last mentioned that this book treats, and it is hoped that it will fill the needs of the growing group of educators who realize the great importance of teaching "sight recognition" of minerals to engineering students or others who study mineralogy merely for its cultural value. In order to conserve the students' time and

energy, everything not germane to the end sought — the acquisition of information useful in the “sight recognition” of minerals — has been omitted, and no hesitation has been felt in departing from current usage when it seemed desirable in order to secure simplicity and clarity.

The system followed is not an untried experiment, but was introduced many years ago by Dr. H. B. Patton in the Colorado School of Mines where it has been taught with marked success, and from which it has been carried by graduates to a number of other institutions. This system includes the study of numerous wooden, cardboard, or plaster models of crystals, together with oral quizzes involving the instantaneous identification of the forms represented on such models, and discussions of the theoretical aspects of the subject. After models belonging to a certain system or group of systems have been studied and a sufficient knowledge of them revealed in the quiz the student takes up the determination of natural crystals of the same degree of symmetry; and the study of crystal models and of corresponding natural crystals alternate throughout the course. If this plan is followed, it will be necessary for the student to familiarize himself with the matter presented in Chapter IX before attempting to work with natural crystals.

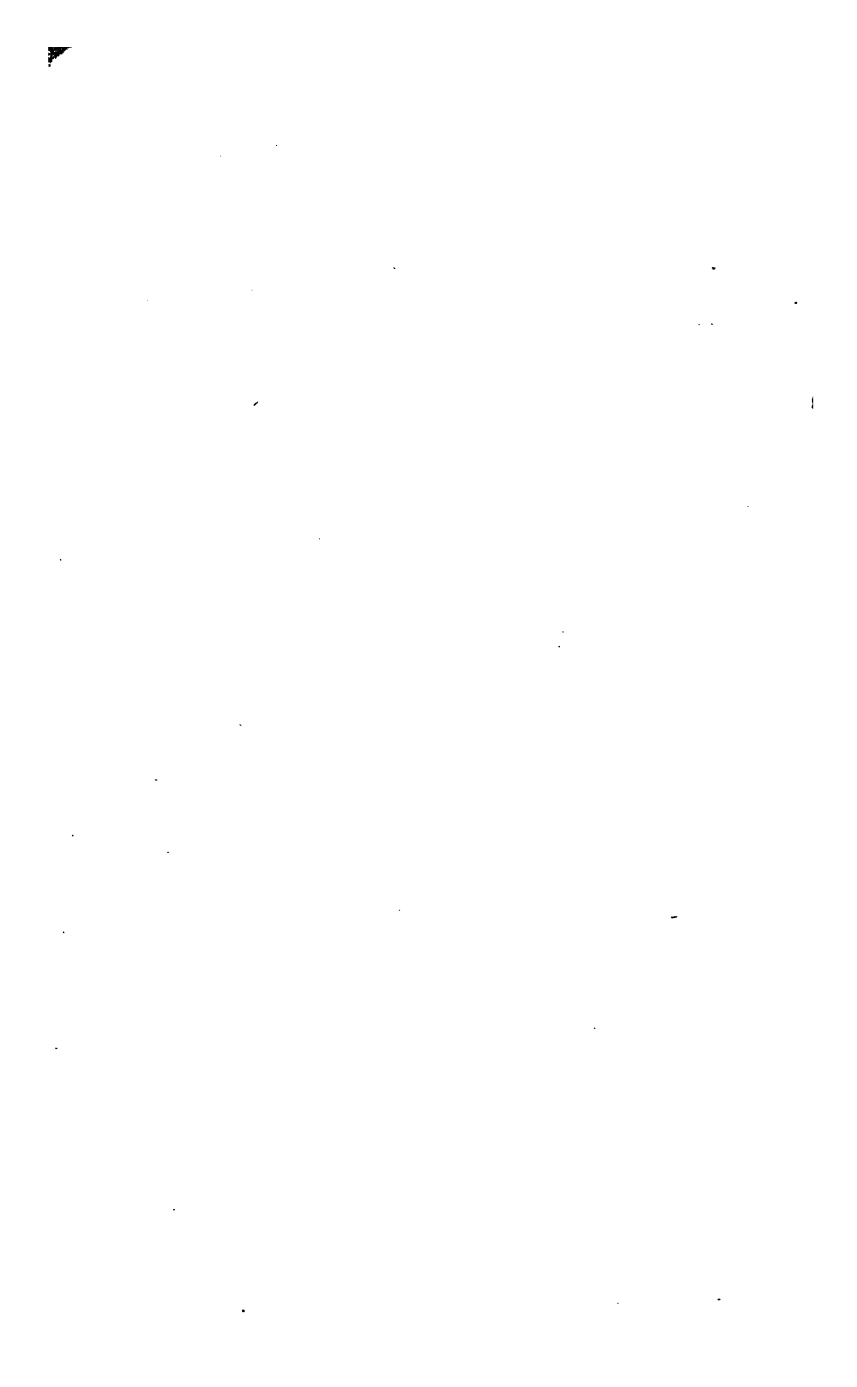
The author desires to acknowledge his great indebtedness to Patton's “Lecture Notes on Crystallography,” and, to a lesser extent, to Bayley's “Elementary Crystallography” for ideas and even definitions and descriptions embodied in this book. While most of the illustrations are original, many are



copied without other acknowledgment than this from Bayley's "Elementary Crystallography," Dana's "System of Mineralogy," and Moses and Parsons' "Mineralogy, Crystallography, and Blow-pipe Analysis."

G. MONTAGUE BUTLER

TUCSON, ARIZONA, *September* 15, 1917.



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# A Manual of Geometrical Crystallography

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## CHAPTER I

### INTRODUCTORY CONCEPTIONS

#### **A Mineral Defined.**

A mineral is a naturally occurring, homogeneous, inorganic substance.

Diamonds, white mica (muscovite), native gold, and flint are illustrations of minerals; while a silver coin, granite (consists essentially of two minerals, orthoclase and quartz, so is not homogeneous), coal (is organic material), and window glass are not minerals although they belong to the so-called "mineral world" as distinguished from the "animal and vegetable worlds."

#### **Structure of Minerals.**

*Molecules:* Minerals, as well as all other substances, are made up of extremely small particles called molecules which in any homogeneous substance are all alike in composition, size, and weight, but which are unlike in the particulars mentioned in different substances. They are believed to be separated from one another to some extent even in the hardest and densest materials. There is a tendency

for each molecule to be held in position with respect to adjacent molecules by certain forces of mutual attraction, against which is opposed a tendency for each molecule to move in a straight line. The relative strength of these two tendencies is believed to determine whether a substance is a gas, a liquid, or a solid.

*Amorphous Structure Defined:* A substance is said to possess an amorphous structure or to be amorphous when its constituent molecules are arranged according to no definite fashion or pattern. Presumably they lie at unequal distances with respect to each other, and lines joining their centers do not meet in fixed angles. If a box of oranges be dumped helter-skelter into a basket and each orange be considered analogous to an enormously magnified molecule, a good conception of the structure of an amorphous substance can be obtained.

Natural and artificial glasses are excellent illustrations of amorphous materials, but not a few minerals also possess this structure.

*Crystalline Structure Defined:* A substance is said to possess a crystalline structure or to be crystalline when the constituent molecules are arranged in some definite fashion or pattern. A box of oranges of equal size packed in even rows and layers is analogous to a crystalline substance in which each orange corresponds to a molecule, but it should not be understood that all crystalline materials have a structure resembling in detail the illustration just given.

Crystalline substances, while they may resemble amorphous ones very closely, at least superficially,

can usually be recognized by the presence of cleavage (see p. 142) or distinctive optical, electrical, thermal, or other physical properties which prove that in crystalline materials there are certain directions along which forces or agents act with quite different effects from those produced in other directions. Thus a sphere of glass (amorphous) when heated expands equally in all directions and remains perfectly spherical; while a sphere of emerald (crystalline) if similarly heated will be distorted and will become ellipsoidal due to the fact that the coefficient of expansion in one direction differs from that in all others.

The majority of minerals as well as many artificial substances have crystalline structures.

A most useful characteristic of a crystalline substance results from the fact that at the time of its formation it shows a more or less pronounced tendency to form a body bounded wholly or partially by plane surfaces or faces. Such a partial or complete polyhedron is called a crystal; and, if several such crystals develop in contact with or close proximity to one another, a group of crystals results.

While no simple definition distinguishing between single crystals and crystal groups can be offered, there should be little chance of a misconception arising through the use of the following definition.

#### **A Crystal Defined.**

A crystal is a crystalline substance bounded wholly or partially by natural plane surfaces called faces which have not been produced by external forces.

From what has been said it must be evident that a crystal always has a crystalline structure, but it is equally important to remember that crystalline substances do not by any means always occur in crystals. These are the exception rather than the rule, and develop only when conditions are favorable. When faces are lacking, other features (such as the presence of cleavage) or physical tests must be used to determine whether a substance is crystalline or amorphous.

*Formation of Crystals:* Crystals may form in two ways, namely, through deposition from solutions (including fusions which are now recognized as forms of solution) and from the sublimed (gaseous) condition. In either case, a solid molecule having formed, growth occurs through the addition of myriads of other molecules which surround the first according to some definite geometric plan. If the resulting crystal is in suspension in a gas, vapor, or liquid, it will be entirely bounded by crystal faces; otherwise, only those portions that are surrounded by the gas, vapor, or liquid will develop in the manner outlined.

Crystals are often formed in the manufacture of artificial substances, and these are subject to the same laws that apply to mineral crystals.

#### **Crystallography Defined.**

Crystallography is the science that deals with crystals.

Three branches of this science are recognized. These are geometrical crystallography, physical crystallography, and chemical crystallography. The scope of each is suggested by its name. The student



of determinative mineralogy is most concerned with the first of these branches, and this manual deals almost entirely with that phase of the science.

The study of crystals has great practical value to a mineralogist since it has been found that each crystalline mineral occurs in crystals whose shapes resemble each other very closely, and are, indeed, frequently almost identical no matter where found. Further, it is true that crystals of different minerals are usually quite dissimilar, and it is often possible for one familiar with crystallography to distinguish easily between two crystallized minerals which, except for the difference in their crystals, resemble each other very closely. Crystallographic terms are also employed in describing features used as criteria in determinative mineralogy.

## FUNDAMENTAL DEFINITIONS

Some of the definitions that follow apply only to geometrically perfect crystals or crystal models. In the cases of incomplete and distorted crystals (discussed later) these conceptions will have to be modified as suggested in the concluding chapter.

### **A Symmetry Plane Defined.**

A symmetry plane is any plane which divides an object in such a way that *any* line drawn perpendicular thereto, if extended in both directions, will strike the exterior of the object in similar points which are equidistant from the dividing plane.

Thus, in Fig. 1,  $AA'$  is a symmetry plane because a perpendicular drawn to it at any point, as at  $B$ ,

strikes the exterior at  $C$  and at  $C'$  which are similar points equidistant from the plane.  $MM'$  is not a symmetry plane, however, since a perpendicular erected to it at  $N$  strikes the exterior at  $O$  and  $O'$

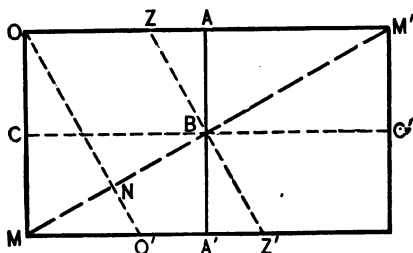


FIG. 1.

which are neither similar points (one is at a corner and the other lies on an edge) nor are they equidistant from the plane under consideration. It should be observed, however, that the perpendicular erected at  $B$  strikes the exterior at  $Z$  and  $Z'$  which are similar points and are equidistant from  $MM'$ . The definition states, however, that, in order that a given plane shall be a symmetry plane, the test given must be applicable to *any perpendicular one chooses to select*, and it has already been shown that it does not hold in the case of  $OO'$ .

The object used in the illustrations just given is a surface, but the same considerations apply to symmetry planes in solids.

Another definition of a symmetry plane especially useful in the case of solids is the following:

A symmetry plane is any plane so situated that, if it were a mirror, the reflection of the portion in

front of the mirror would seem to coincide exactly with the part behind.

From what has been said it is easy to see that, while symmetry planes divide objects into halves identical in shape and size, the mere fact that an object is so divided does not prove that the dividing plane is a symmetry plane. In Fig. 1 plane  $MM'$  divides the object into equal halves, but is not a symmetry plane.

As a corollary of the foregoing, it may be said that a symmetry plane is any plane that divides an object in such a way that every edge, corner, and face on one side of the plane is exactly balanced by identical edges, corners, and faces *directly opposite* on the other side of the plane.

All symmetry planes may be called either principal symmetry planes or secondary (sometimes called common) symmetry planes, as is explained later.

#### **A Symmetry Axis Defined.**

A symmetry axis is the line or direction perpendicular to a symmetry plane and passing through the center of the object.

#### **A Principal Symmetry Plane Defined.**

A principal symmetry plane is a symmetry plane perpendicular to which lie at least two *interchangeable* symmetry planes (either principal or secondary).

It should be remembered that there are three parts to this definition, and that any principal symmetry plane must conform to *all* of them. First, it must divide an object symmetrically — be a symmetry plane as already defined. Second, at

least two other symmetry planes existing in the object must be perpendicular to the plane under consideration (these need not be perpendicular to each other). Third, the two or more symmetry planes perpendicular to the one under consideration must be interchangeable. This third condition is the one most frequently misunderstood or overlooked by beginners. Attention should, then, be especially directed to the following paragraph.

**Interchangeable Symmetry Planes and Axes Defined.**

Two symmetry planes or axes are said to be interchangeable when one plane or axis may be placed in the position of the other plane or axis without apparently altering the appearance or position of the object.

**A Principal Symmetry Axis Defined.**

A principal symmetry axis is a symmetry axis perpendicular to a principal symmetry plane.

**A Secondary (or Common) Symmetry Plane Defined.**

A secondary symmetry plane is any symmetry plane that does not possess the characteristics of a principal symmetry plane as already defined.

**A Secondary Symmetry Axis Defined.**

A secondary symmetry axis is a symmetry axis perpendicular to a secondary symmetry plane.

**An Interfacial Angle Defined.**

An interfacial angle is an angle formed at the intersection of two faces or the planes of two faces. It must be measured perpendicular to the edge

formed by the intersection of the two faces; or, if the faces do not intersect in an edge, the measurement must be made perpendicular to the imaginary line located at the intersection of the planes of the two faces.

**A Zone Defined.**

A zone is a group of faces in the form of a belt or band which extends around a crystal in such a way that the edges formed by the mutual intersections of the faces are all parallel.

**A Zonal Axis Defined.**

A zonal axis is a line through the center of a crystal parallel to the faces of a zone.

**Replaced Edges and Corners Defined.**

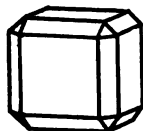
A face is said to replace an edge when that face is substituted for, and lies parallel to, the edge, yet is *not equally inclined* to the two faces whose intersection would form that edge.

Similarly, a face may be said to replace a corner formed by the intersection of three or more faces when it is substituted for that corner, but is *not equally inclined* to at least one set of similar faces whose intersection would form that corner.

**Truncated Edges and Corners Defined.**

A face is said to truncate an edge when it is substituted for that edge in such a way as to be parallel to it and to make *equal angles* with the faces whose intersection would form that edge. Fig. 2 shows a crystal with truncated edges.

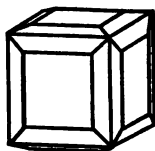
Similarly, a face may be said to truncate a corner when it is substituted for that corner and makes *equal angles* with all similar faces whose intersections would form that corner. Fig. 2 shows a crystal with truncated corners.



#### **Beveled Edges Defined.**

Two faces are said to bevel an edge if they replace the edge in such a way that equal angles are formed between each replacing face and the adjacent faces whose intersection would form the edge. Fig. 3 shows a crystal with beveled edges.

FIG. 2. — Hexahedron (cube) with edges truncated by the dodecahedron, and corners truncated by the octahedron.



#### **A Crystal System Defined.**

All those crystals which contain the same number and kind of symmetry planes (together with others produced by the suppression of certain faces in accordance with definite laws, which may be regarded as 'modifications of these') are said to belong to the same crystal system.

FIG. 3. — Hexahedron (cube) with edges bevelled by the tetrahexahedron.

#### **Number and Names of the Crystal Systems.**

Any crystal may be placed in one of six crystal systems. Of these there are 32 subdivisions or classes, but few or no minerals are known to occur in some of these, so familiarity with all of them is unnecessary.

The six crystal systems are as follows:<sup>1</sup>

Number and kind of symmetry planes in crystals with the fully developed symmetry of the system.		Name of the system.
Principal.	Secondary.	
3	6	Isometric
1	6	Hexagonal
1	4	Tetragonal
0	3	Orthorhombic
0	1	Monoclinic
0	0	Triclinic

Any one crystalline mineral species always occurs in crystals characterized by the presence of a definite number and kind of symmetry planes, which is equivalent to saying that its crystals always belong to a certain one of the subdivisions of the above-mentioned crystal systems. Crystals containing the same kind and number of symmetry planes are said to show the same *degree of symmetry*.

<sup>1</sup> As it is absolutely necessary that the student should be able to recognize symmetry planes and to distinguish between principal and secondary symmetry planes, it is desirable that, before proceeding further, a number of crystal models should be separated, first into three groups each containing the same number of principal symmetry planes, and then into the six crystal systems, to do which the number of secondary symmetry planes must also be considered. Wooden models for this work are manufactured by Dr. F. Krantz, Bonn on Rhine, Germany, and sold at an average price of less than \$0.50 each.

**Designating the Position of Planes in Space.**

The position of any plane may be defined by ascertaining its relation to three fixed lines or axes intersecting in a common point called the *origin*. This may be done by determining the distance and direction from the origin to the point at which the plane cuts each axis. As crystals are bounded by faces which are circumscribed portions of planes, the positions of such faces may be given by referring them to such a system of axes.

**Crystal Axes Defined.**

Crystal axes are fixed lines or directions to which crystal faces are referred for the purpose of ascertaining their mutual relationships.

**General Rule for Choosing Crystal Axes.**

Select the crystal axes so that they coincide where possible with symmetry axes, giving the preference to principal symmetry axes; but when an insufficient number of symmetry axes are present choose lines passing through the center of the crystal and parallel to prominent crystallographic directions, preferably edges. The crystal axes should intersect at as nearly right angles as possible in all systems but the hexagonal in which it is convenient to have the horizontal axes intersect at angles of  $60^\circ$  and  $120^\circ$ , instead of  $90^\circ$ .

**The Terms Crystal and Symmetry Axes not Synonymous.**

Care should be exercised not to confuse the terms crystal axes and symmetry axes. While it is true



that these sometimes coincide, they do not by any means always do so. Some symmetry axes are never used as crystal axes; and many crystal axes are not symmetry axes at all.

### **Designation and Use of Crystal Axes.**

It is customary to call the crystal axis extending from front to back the *a* axis, the one from right to left the *b* axis, and the vertical one the *c* axis. Interchangeable crystal axes are represented by the same letter, however.

It will later be made plain that the faces on any crystal may be separated into groups each of which is characterized by the fact that its faces (or the planes of the faces) intersect all the crystal axes at distances from the origin which bear the same fixed ratios to each other. It has been observed that, in the case of any given mineral species, certain such groups are comparatively common while others are less common or rare. It is the usual presence of certain such groups of faces that causes the crystals of any given species to resemble each other very closely, and makes it possible to classify instantly many minerals occurring in crystals.

### **Ground-form or Unit-form Defined.**

The ground-form or unit-form of the crystals of any mineral species is the most commonly occurring group of faces that intersect all the crystal axes at finite distances from the origin which distances bear the same fixed ratios to each other. In the isometric system the octahedron (see p. 19) is called the ground-form.

**Unit Axial Lengths Defined.**

The distances from the origin at which the faces (or faces extended) of the ground-form intersect the crystal axes are considered the unit axial lengths of those axes, provided that such a scale be used as will make the length of at least one of these axial lengths unity. This definition applies to all systems but the isometric. In that system the unit axial length is the shortest one of the three distances measured from the origin to the points where a face (or the plane of a face) intersects the crystal axes.

Practically, of course, any scale can be used in making the measurements mentioned in the last paragraph, since, for instance, if the distances measured in any scale on the  $a$ ,  $b$ , and  $c$  axes are, respectively, 1.817, 1.112, and 1.253, and it is desired to have the  $b$  axial length unity, this may be brought about without affecting the ratio between the expressions by dividing each of the three expressions by the value for  $b$ . If this is done, the results will be 1.634, 1.000, and 1.125 which are the unit axial lengths of the crystals of the mineral selected as an illustration (sylvanite).

The letters  $a$ ,  $b$ , and  $c$  are used not only to designate the crystal axes, but also to represent the unit axial lengths of these axes.

The distances from the origin at which faces (or faces extended) other than those belonging to the ground-form cut the axes are expressed in terms of the unit axial lengths, as  $4a$ ,  $2b$ , and  $1c$ . If it is desired to have unity for the coefficient of  $b$ , this may be secured by dividing each expression by the

coefficient of  $b$ , which reduces the expressions to  $2a$ ,  $1b$ , and  $\frac{1}{2}c$ .

#### **A Parameter Defined.**

A parameter is the distance from the origin to the point where a face (or a face extended) cuts a crystal axis, measured in terms of the unit length of that axis. Thus, in the illustration given in the preceding paragraph, 2, 1, and  $\frac{1}{2}$  are the parameters of the face under consideration on the  $a$ ,  $b$ , and  $c$  axis, respectively. It is customary to use  $m$ ,  $n$ , and  $p$  as general expressions for parameters. A face parallel to an axis will intersect that axis at infinity, and will have infinity ( $\infty$ ) for its parameter on that axis.

#### **The Law of Rationality of Parameters.**

Parameters are always rational, fractional or whole, small or infinite numbers.

#### **Crystal Form Defined.**

A crystal form is a group of faces with identical parameters all of which are necessary to complete the symmetry of the system.

In explanation of this definition, it may be stated that in studying any system of crystals, if we assume the presence of a face or plane of given parameters, there must be present a definite number of other faces with identically the same parameters in order that the complete symmetry of the system may be shown. Such a group of faces is technically known as a crystal form. It will later be shown that there are *seven* distinctly different forms in each system and in each subdivision of a system.

**Crystal Form and Shape Differentiated.**

The student should be careful not to confuse the terms "form" and "shape" as applied to crystals. A crystal may have the general appearance of a cube, for instance, yet bear no faces with the parameters characteristic of the crystal form known as the cube. It may still, with propriety, be said to have a cubical shape, although the crystal form known as the cube is not represented upon it.

**Symbol Defined.**

A symbol in the Weiss system, of which a slight modification is used in this book, is the product of the parameters of a face and the corresponding unit axial lengths, arranged in the form of a ratio, as  $na : b : mc$ .

Since every face of any one form has the same parameters and unit axial lengths, it follows that the symbols of any face may be regarded as the symbol of the form of which that face is a part.

Several other systems of symbols are in more or less widespread use, and are presented in the more extended textbooks on crystallography. Lists of such symbols without further explanation are in this book appended to the description of each crystal system.

**Law of Axes.**

The opposite ends of crystal axes (as well as of symmetry axes) must be cut by the same number of similar crystal faces similarly arranged.

The importance of this law will be understood when the monoclinic and triclinic systems are studied.

**Holohedral, Hemihedral, and Tetartohedral Forms Defined.**

*Holohedral Forms:* When a form has the full symmetry of the system to which it belongs (see p. 11) it is said to be holohedral.

*Hemihedral (half) Forms:* A hemihedral form may be conceived to be developed by dividing a holohedral form by means of a certain set or sets of symmetry planes into a number of parts, then suppressing all faces *lying wholly within alternate parts* thus obtained, and extending all the remaining faces until they meet in edges or corners.

*Tetartohedral (quarter) Forms:* Tetartohedral forms may be conceived to be developed from holohedral ones by the simultaneous application of two different types of hemihedrism. These may be regarded as the half forms of half forms.

**Hemimorphic Crystals Defined.**

A hemimorphic crystal is one in which the law of axes is violated so far as one crystal axis is concerned; that is, the opposite ends of one crystal axis *are not* cut by the same number of similar faces similarly arranged.

Comparatively few minerals occur as hemimorphic crystals.

## CHAPTER II

### ISOMETRIC SYSTEM

#### HOLOHEDRAL DIVISION

##### **Symmetry.**

The holohedral division of the isometric system is characterized by the presence of three interchangeable principal symmetry planes and six interchangeable secondary symmetry planes. The former intersect at angles of  $90^\circ$ , and the latter at  $60^\circ$ ,  $90^\circ$ , and  $120^\circ$  angles. The two classes of symmetry planes are so arranged that every  $90^\circ$  angle between principal symmetry planes is bisected by a secondary symmetry plane.

##### **The Selection, Position, and Designation of the Crystal Axes.**

In accordance with the general rule (see p. 12), the crystal axes in the isometric system are chosen so as to coincide with the principal symmetry axes. There are, then, in the isometric system three interchangeable crystal axes which are at right angles to each other. One is held vertically, and one so as to extend horizontally from right to left; the other must then extend horizontally from front to back. Since all of these axes are mutually interchangeable, each is called an *a* axis.

When a crystal is so held that the crystal axes extend in the proper direction as viewed by the observer it is said to be *oriented*.

**Orienting Crystals.**

Holohedral isometric crystals are oriented by holding a principal symmetry plane so that it extends vertically from front to back; then rotating the crystal around the principal symmetry axis perpendicular to this plane until another principal symmetry plane extends vertically from right to left, and a third such plane lies horizontally. The crystal axes will then extend in the proper directions.

**An Octant Defined.**

An octant in all systems but the hexagonal is one of the eight parts obtained by dividing a crystal by means of three planes each of which contains *two* crystal axes.

**Holohedral Isometric Forms Tabulated.**

The holohedral isometric forms, together with other data relating to each, are given in the following table:

		Symbol.	Name.	Number of faces.
Three axes cut alike		$a : a : a$	Octahedron (Fig. 4)	8
Two axes cut alike	Two axes cut at a distance < the other	$a : a : ma$	Trisoctahedron (Fig. 5)	24
		$a : a : \infty a$	Dodecahedron (Fig. 6)	12
	Two axes cut at a distance > the other	$a : ma : ma$	Trapezohedron (Fig. 7)	24
		$a : \infty a : \infty a$	Hexahedron (cube) (Fig. 8)	6
Three axes cut unlike		$a : ma : na$	Hexoctahedron (Fig. 9)	48
		$a : ma : \infty a$	Tetrahexahedron (Fig. 10)	24

*Notes.* — In the isometric system,  $m$  and  $n$  are never less than unity.

In the isometric system, it is customary to abbreviate the symbols by omitting the letter  $a$  and the ratio sign as  $1m$  for  $a : ma : na$ .

The symbol  $a : a : ma$ , for instance, is read  $a, a, ma$  without mention of the proportion signs.

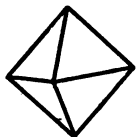


FIG. 4. — Octahedron.

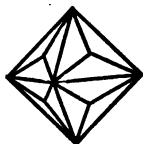


FIG. 5. — Trisoctahedron.

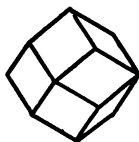


FIG. 6. — Dodecahedron.

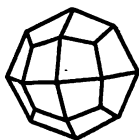


FIG. 7. — Trapezohedron.

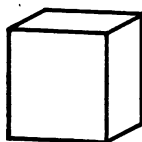


FIG. 8. — Hexahedron (cube).

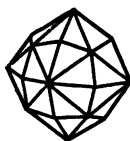


FIG. 9. — Hexoctahedron.

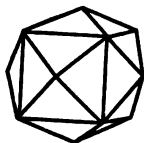


FIG. 10. — Tetrahexahedron.

**Synonyms for the Names of the Holohedral Isometric Forms.**

Octahedron — none.

Trisoctahedron — trigonal trisoctahedron.

Dodecahedron — rhombic dodecahedron.

Trapezohedron — icositetrahedron or tetragonal trisoctahedron.



Hexahedron — cube.

Hexoctahedron — none.

Tetrahexahedron — none.

**Method of Determining Holohedral Isometric Forms  
by the Use of Symbols.**

After properly orienting the crystal in the manner already described select any face in the upper right octant facing the observer, and ascertain the relative distances from the origin at which its plane cuts the three crystal axes. This may be done mentally or by laying a card upon the face and using a pencil to represent each axis in turn. If it appears that the three axes are cut equally, the symbol of the face (and of the form of which it is a part) is  $a : a : a$ . By referring to the table given on p. 19, which should be memorized as soon as possible, it is seen that the form is the octahedron. Similarly, if the plane of the face cuts one axis comparatively near the center of the crystal, and the other two at greater, but equal, distances, the symbol is  $a : ma : ma$ , and the form represented is the trapezohedron.

If more than one form is represented on the crystal (see p. 25), each may be determined in the same way. By using this method, it may be found that a crystal like Fig. 2 shows the hexahedron, dodecahedron, and octahedron; and, no matter how complex a crystal may be, the forms represented upon it may thus be readily ascertained.

After the name of a form has been determined by the method suggested the result may be checked by noting whether the form in question has the requisite

number of faces. To determine the number of faces, it is only necessary to count those lying in one octant and to multiply this sum by eight. If it is found, for instance, that three half ( $1\frac{1}{2}$ ) faces lie within an octant, the form has eight times one-and-a-half, or twelve faces, and is a dodecahedron.

**Suggestions for Attaining Facility in the Recognition of Forms.**

While it is permissible and, in fact, almost necessary at first to use the symbols for the purpose of determining crystal forms, this method is too slow to be wholly satisfactory, and should quickly be displaced by the one outlined below, which has for its aim the instantaneous determination of forms through familiarity with the position or slope of one or more of their faces.

In order to use this method, orient the crystal, and study the face or faces of different shape or size in or near the upper right octant facing the observer. Then determine which of the following descriptions (which should be learned at once) apply to the face or faces seen.

*Cube:* A horizontal face on top of the crystal. The faces of the cube are parallel to the principal symmetry planes.

*Dodecahedron:* A face parallel to the right and left axis and sloping down toward the observer at a steep angle —  $45^\circ$  from the horizontal. The dodecahedron has three faces lying in the octant with an edge running from above the center of the octant up toward the vertical axis, but these faces do not lie *wholly within* the octant. (Compare with the tris-

octahedron.) The faces of the dodecahedron are parallel to the secondary symmetry planes.

*Tetrahexahedron:* A face parallel to the right and left axis and sloping down toward the observer at a relatively gentle angle — less than  $45^\circ$  from the horizontal. The tetrahexahedron has six faces lying in the octant, but they do not lie *wholly within* the octant. (Compare with the hexoctahedron.)

*Octahedron:* A single face in the center of the octant, sloping steeply down from the vertical axis — at an angle of  $54\frac{3}{4}^\circ$  with the horizontal.

*Trapezohedron:* Three faces lying *wholly within* the octant and so arranged that a *face* slopes above the center of the octant up toward the vertical axis at an angle less steep than that shown by the octahedron. It is often useful to remember, further, that two faces forming part of the same trapezohedron may intersect *below the center* of the octant in an edge that points directly toward the vertical axis.

The trapezohedron is most apt to be confused with the trisoctahedron, described below, and the two descriptions should be carefully compared.

*Trisoctahedron:* Three faces lying *wholly within* the octant and so arranged that in the unmodified form an *edge* slopes *above* the center of the octant up toward the vertical axis. Even when so modified that the edge is lacking, it is easy to see that two faces extended would intersect in such an edge.

*Hexoctahedron:* Six faces lying *wholly within* the octant. As with the trisoctahedron and dodecahedron, there is, on the unmodified form, an edge running above the center of the octant up toward the vertical axis.

**Fixed and Variable Forms Defined.**

*A Fixed Form:* A fixed form is one that has no variable parameter ( $m$ ,  $n$ , or  $p$ ) in its general symbol. The octahedron, dodecahedron, and cube are fixed holohedral isometric forms.

The fixed forms never vary in the slightest degree in appearance, and their interfacial angles are fixed quantities.

*A Variable Form:* A variable form is one that has one or more variable parameters ( $m$ ,  $n$ , or  $p$ ) in its general symbol. That is, the symbol contains one or more parameters to which various values, such as 2,  $2\frac{1}{2}$ , 3, etc., may be assigned without affecting the naming of the form. - The trisoctahedron, trapezohedron, hexoctahedron, and tetrahexahedron are variable holohedral isometric forms.

Two or more variable forms of the same name may differ considerably in shape if the values of the variable parameters in their symbols are materially different. For instance, Fig. 11 shows two trapezohedrons that do not resemble each other very closely. This is because the symbol of the one to the left is  $a : 2a : 2a$ , while that of the one to the right is  $a : 3a : 3a$ .

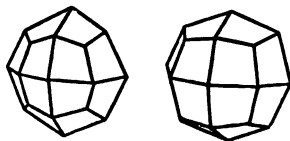


FIG. 11. — Trapezohedrons with symbols (on left)  $a : 2a : 2a$  and (on right)  $a : 3a : 3a$ .

**Interfacial Angles of the Fixed Forms.**

Octahedron,  $109^{\circ} 28\frac{1}{4}'$  (usually given as  $109\frac{1}{2}^{\circ}$ ).

Dodecahedron,  $60^{\circ}$ ,  $90^{\circ}$ , and  $120^{\circ}$ .

Cube,  $90^{\circ}$ .

The interfacial angles of the fixed forms are often called the *fixed angles* of a system.

### **Combination of Forms.**

It will be found that, while some crystals are bounded by a single crystal form, the majority exhibit more than one such form. When this is the case the shapes of the faces shown in Figs. 4 to 10, inclusive, may be decidedly changed, but their symbols will remain unaltered.

### **Determination of the Number of Forms on a Crystal.**

On a perfectly developed crystal there are as many forms as there are differently shaped and dimensioned faces. This is equivalent to saying that, whether unmodified or modified by the presence of other forms, all the faces of a given crystal form on a crystal are of identically the same shape and size.

### **Repetition of Forms on a Crystal.**

Each of the fixed forms can occur but once on a crystal.

Each of the variable forms may occur an indefinite number of times on a crystal. Theoretically, one might say an infinite rather than an indefinite number of times, but, practically, the number of times a variable form is repeated on a crystal is usually small.

In order that a given variable form may occur more than once on a crystal, it is, of course, necessary that the symbols of the various forms of the same name differ as regards the values of the variable

parameter or parameters. Thus, the trapezohedron  $a : 2a : 2a$  can occur but once on a crystal, but it may be combined with the  $a : 1\frac{1}{2}a : 1\frac{1}{2}a$  trapezohedron, the  $a : 3a : 3a$  trapezohedron, etc.

Holohedral isometric models showing repeated forms are difficult to obtain.

### Modification of Fixed Forms.

It will be found useful to memorize the names of the forms which truncate and bevel the edges, and truncate the corners, of each of the fixed forms, as set forth in the following table:

Form modified.	Form truncating edges.	Form beveling edges.	Form truncating corners.
Octahedron Dodecahedron Cube	dodecahedron trapezohedron dodecahedron	trisoctahedron hexoctahedron tetrahexahedron	cube cube and octahedron octahedron

### The Triangle of Forms.

It will be found advantageous to arrange the crystal forms around a triangle as shown in Fig. 12. The fixed forms are at the corners of this triangle, while the variable ones completely fill its sides and center. Theoretically there is an infinite number of trisoctahedrons along the left-hand side, each of which differs from the others as regards the magnitude of the variable parameter. Similarly the other sides of the triangle are filled with infinite numbers of trapezohedrons and tetrahexahedrons, while the interior of the figure should be conceived as completely filled with an infinite quantity of hexoctahedrons.

**Utilization of the Triangle of Forms.**

The triangle may be used to identify small, obscure forms replacing or truncating the edges between larger and more easily recognized ones, since a form lying in a straight line between two other forms on

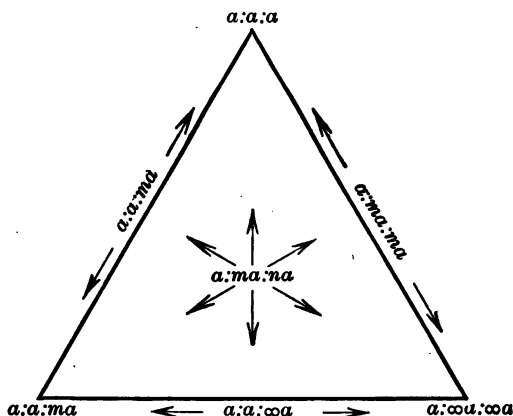


FIG. 12. — "Triangle of Forms."

the triangle will replace or truncate the edge between those same forms on a crystal. For instance, suppose a small face replaces the edge between a dodecahedron and a cube. Reference to the triangle shows that the only form lying in a straight line between the dodecahedron and the cube is a tetrahexahedron. The tetrahexahedron must then be the form whose name is sought. From what was said in the preceding paragraph, it must be evident that an indefinite number (theoretically infinite) of tetrahexahedrons may replace the edge between a cube and dodecahedron. Similarly, it may be

ascertained that nothing but hexoctahedrons can replace the edge between a trapezohedron and a dodecahedron, or between an octahedron and a tetrahexahedron; while the only form that can replace the edge between two trisoctahedrons is another trisoctahedron.

### Limiting Forms Defined.

Limiting forms are those forms which a variable form approaches in appearance ("shape") as the variable parameter (or parameters) in its symbol approaches either unity or infinity. Thus, a trapezohedron ( $a : ma : ma$ ) approaches an octahedron ( $a : a : a$ ) in symbol and in shape as  $m$  approaches unity, and a cube ( $a : \infty a : \infty a$ ) as  $m$  approaches  $\infty$ . The octahedron and cube are, then, said to be limiting forms of the trapezohedron.

Where a variable form is situated on one side of the triangle of forms, the two forms at the extremity of that side are its limiting forms. The hexoctahedron, in the interior of the triangle, has all the other six forms as its limiting forms.

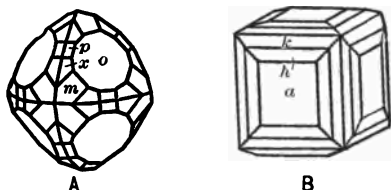


FIG. 13. — Holohedral isometric crystals.

A: Octahedron ( $o$ ), trapezohedron ( $m$ ), trisoctahedron ( $p$ ), and hexoctahedron ( $x$ ).

B: Cube ( $a$ ), and two tetrahexahedrons ( $h$  and  $k$ ).



**TETRAHEDRAL (INCLINED) HEMIHEDRAL  
DIVISION****Development or Derivation of the Forms.**

Tetrahedral hemihedral isometric forms may be conceived to be developed by dividing each holohedral form by means of the three principal symmetry planes into eight parts (octants), then suppressing all faces lying wholly within alternate parts thus obtained, and extending all the remaining faces until they meet in edges or corners.

**Symmetry.**

Tetrahedral hemihedral forms possess only the six secondary symmetry planes characteristic of the isometric system, since the method of development outlined necessarily destroys the principal symmetry planes.

In general, it may be said that *the planes used for dividing holohedral forms in the development of hemihedral or tetartohedral forms are always destroyed.*

**Selection, Position, and Designation of the Crystal  
Axes.**

The three directions used as crystal axes in the holohedral division are still utilized for the same purpose in the tetrahedral hemihedral division. In other words, three interchangeable directions at right angles to each other are used, one of which is held vertically, another extending horizontally from right to left, and the third extending horizontally from front to back. These are, however, no longer

symmetry axes, as they were in the holohedral division. Each is called an *a* axis, as in the holohedral division.

### Orienting Crystals.

Tetrahedral hemihedral crystals are oriented by holding a symmetry plane (secondary) so that it extends vertically from front to back, then rotating the crystal around the symmetry axis perpendicular to this plane until a second symmetry plane extends vertically from right to left, and, finally, rotating the crystal around a vertical axis  $45^\circ$  either to the right or left. When this has been done the symmetry planes will occupy their proper positions, and the crystal axes will extend in the proper directions.

### Tetrahedral Hemihedral Isometric Forms Tabulated.

Name.	Symbol.	Number of faces.	Form from which derived.
$\pm$ Tetrahedron (Fig. 14).....	$\pm \frac{a : a : a}{2}$	4	octahedron
$\pm$ Trigonal tristetrahedron } (Fig. 15) .....	$\pm \frac{a : ma : ma}{2}$	12	trapezohedron
$\pm$ Tetragonal tristetrahedron } (Fig. 16) .....	$\pm \frac{a : a : ma}{2}$	12	trisoctahedron
$\pm$ Hextetrahedron (Fig. 17)....	$\pm \frac{a : ma : na}{2}$	24	hexoctahedron
Hexahedron (cube) (Fig. 8).....	$\frac{a : \infty a : \infty a}{2}$	6	hexahedron (cube)
Dodecahedron (Fig. 6).....	$\frac{a : a : \infty a}{2}$	12	dodecahedron
Tetrahexahedron (Fig. 10).....	$\frac{a : ma : \infty a}{2}$	24	tetrahexahedron

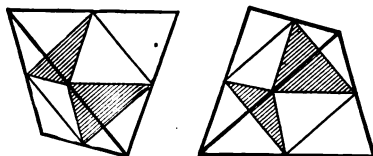


FIG. 14. — Positive (on left) and negative (on right) tetrahedrons containing the forms from which they are derived. The suppressed faces are shaded.

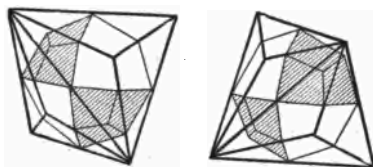


FIG. 15. — Positive (on left) and negative (on right) trigonal tristetrahedrons containing the forms from which they are derived. The suppressed faces are shaded.

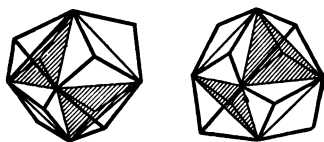


FIG. 16. — Positive (on left) and negative (on right) tetragonal tristetrahedrons containing the forms from which they are derived. The suppressed faces are shaded.

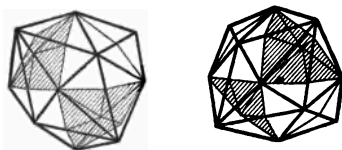


FIG. 17. — Positive (on left) and negative (on right) hextetrahedrons containing the forms from which they are derived. The suppressed faces are shaded.

### Synonyms for the Names of the Tetrahedral Hemihedral Isometric Forms.

Tetrahedron — none.

Trigonal tristetrahedron — tristetrahedron or hemitetragonal trisoctahedron.

Tetragonal tristetrahedron — deltoid dodecahedron or hemitrigonal trisoctahedron.

Hextetrahedron — hemihexoctahedron.

### Symbols of Hemihedral Forms.

The symbol of a hemihedral form is the same as that of the holohedral form from which it is derived excepting that it is written as a fraction with the figure 2 as the denominator. This does not mean that, in the case of hemihedral forms, the axes are intersected at half the holohedral axial lengths, but it is merely a conventional method of indicating that the symbol is that of a half (hemihedral) form. The symbol  $\frac{a : a : a}{2}$  is read  $a, a, a$  over 2.

### Positive (+) and Negative (−) Forms Distinguished.

All those forms produced by the suppression of faces lying within *the same set* of alternating octants are said to be of the same sign (+ or −). It is customary to consider those forms with faces largely or entirely included within the upper right octant facing the observer as +, while those with faces in the upper left octant are −. In reality, a + tetrahedron differs in no way from a − tetrahedron excepting in position; and a tetrahedron may be held in either the + or − position at will. It is customary to hold a crystal in such a way as to bring the larger and more prominent faces principally or

entirely into the upper right octant facing the observer, which will make these forms + ones.

If the sign of a form is not specifically stated to be -, it is always assumed that the form is +.

The forms on a crystal may be all of the same sign, or + and - forms may be combined.

If a + and a - form of the same name and with identical parameters are equally developed, the combination will have the exact external shape of a holohedral form. Thus, a + and a - tetrahedron equally developed will yield an octahedron. On natural crystals equally developed + and - forms often differ in that the faces of one may be brilliant, and the other dull; or one may be striated, and the other unstriated (see p. 138); or one may striate another form (see p. 139), and the other fail to do so.

#### **Method of Determining Tetrahedral Hemihedral Isometric Forms by the Use of Symbols.**

After properly orienting the crystal in the manner already described the cube, dodecahedron, and tetrahexahedron may be identified easily by applying the rules already given for the determination of holohedral forms of the same name. The other four forms may be recognized by determining the symbol of any face in the manner described in the discussion of holohedral forms, dividing this symbol by 2, and then ascertaining from the table the name of the form possessing this symbol.

#### **Suggestions for Attaining Facility in the Recognition of the Forms.**

Orient the crystal and determine which of the following descriptions (which should be learned at

once) apply to the face or faces of different shape or size seen. Call the forms + or - according to the rules already set forth. It is assumed that the student is already familiar with the rules for recognizing those forms identical in shape with the holohedral ones (see p. 22).

*Tetrahedron:* A single face in the center of the octant, sloping steeply down from the vertical axis — at an angle of  $54\frac{3}{4}^{\circ}$  with the horizontal.

*Trigonal Tristetrahedron:* Three faces in an octant (although not necessarily wholly included within the same), so arranged that a *face* slopes above the center of the octant up towards the vertical axis at an angle less steep than is shown by the tetrahedron.

*Tetragonal Tristetrahedron:* Three faces lying in an octant (although not necessarily wholly included therein), so arranged that in the unmodified form an edge slopes above the center of the octant up toward the vertical axis. Even when so modified that the edge is lacking, it is easy to see that two faces extended would intersect in such an edge. No faces of this form are parallel to any crystal axis *or to each other*. This will serve to distinguish this form from the one with which it is most easily confused, namely, the dodecahedron, the faces of which *are* arranged in *parallel pairs*.

*Hextetrahedron:* Six faces lying in an octant (although not necessarily wholly included therein), with no faces parallel to a crystal axis or to each other. The latter portion of this statement will serve to distinguish the form from the tetrahexahedron with which it may be most easily confused.

**Distinction Between Hemihedral and Holohedral Forms of Exactly the Same Shapes.**

The three forms last named in the table of tetrahedral hemihedral forms may differ in no way whatever from the corresponding holohedral forms so far as external shapes are concerned; and a model of a cube, for instance, may with equal propriety be considered either a holohedral or a hemihedral cube. On natural crystals, however, hemihedral cubes, dodecahedrons, and tetrahexahedrons differ in molecular structure and resulting physical properties from the holohedral forms of the same name. Holohedral and hemihedral forms of the same name may often be readily distinguished if striated by other forms (see p. 139).

**Reason Why Some Developed or Derived Forms do not Differ in Shape from the Forms from which They Were Derived.**

In general, it is true that a derived form is identical in shape with the form from which it was developed when no faces of the latter lie wholly within the parts obtained by dividing the form in the manner specified in the rule for developing the derived form.

In the tetrahedral division of the isometric system the three forms which fail to develop into others differing from the holohedral forms in shape are all characterized by the fact that they have infinity in their symbol. This indicates that each face is parallel to one or two of the axes, and must, therefore, lie in two adjacent octants. Since no face lies wholly within an octant, none can be suppressed in accordance with the rule given.

**Law Governing Combination of Forms.**

All the forms on any one crystal must possess the same degree of symmetry as regards their molecular structure.

The law just given is equivalent to the statement that it is impossible to have holohedral and hemihedral, or holohedral and tetartohedral forms on the same crystal; and that it is equally impossible for forms belonging to different hemihedral or tetartohedral divisions to occur together.

It has already been explained that some forms really hemihedral so far as their internal structure is concerned may be identical with holohedral forms in external appearance. These may, of course, be combined with the other hemihedral forms peculiar to the same division of the system. The same statement applies to hemihedral forms which are identical in appearance with hemihedral forms belonging to other divisions; and to tetartohedral forms identical in shape with those in other tetartohedral divisions or with hemihedral or holohedral forms.

**Modification of Fixed Forms.**

Form modified.	Form truncating edges.	Form beveling edges.	Form truncating corners.
+Tetrahedron...	cube	+trigonal tristetrahedron	-tetrahedron
-Tetrahedron...	cube	-trigonal tristetrahedron	+tetrahedron
Cube .....	dodecahedron	tetrahexahedron	±tetrahedron
Dodecahedron ..	±trigonal tristetrahedron	±hextetrahedron	cube and ±tetrahedron



**Miscellaneous.**

All that was said in the discussion of the holohedral division concerning fixed and variable forms, interfacial angles of the fixed forms, combination of forms, determination of the number of forms, repetition of forms on a crystal, the triangle of forms, and limiting forms applies with equal truth to all hemihedral and tetartohedral divisions, excepting that the names of the derived forms must be substituted in these statements for those from which they were derived.

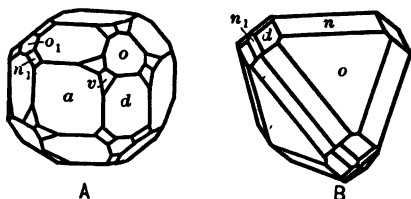


FIG. 18. — Tetrahedral hemihedral isometric crystals.

A: Cube (*a*), dodecahedron (*d*), + and - tetrahedron (*o* and *o*<sub>1</sub>), + hextetrahedron (*v*), and - trigonal tristetrahedron (*n*<sub>1</sub>).

B: + tetrahedron (*o*), + and - trigonal tristetrahedron (*n* and *n*<sub>1</sub>), and dodecahedron (*d*).

## PENTAGONAL (PARALLEL) HEMIHEDRAL DIVISION

### Development or Derivation of the Forms.

Pentagonal hemihedral isometric forms may be conceived to be developed by dividing each of the holohedral forms by means of the six secondary symmetry planes into twenty-four parts, then suppressing all faces lying wholly within alternate parts thus

obtained, and extending the remaining faces until they meet in edges or corners.

### Symmetry.

Pentagonal hemihedral forms possess only the three principal symmetry planes characteristic of the isometric system.

### Selection, Position, and Designation of the Crystal Axes.

The three directions used as crystal axes in the holohedral and tetrahedral hemihedral divisions are still utilized for the same purpose in the pentagonal hemihedral division. In other words, three interchangeable directions at right angles to each other are used, one of which is held vertically, another extending horizontally from right to left, and the other horizontally from front to back. These coincide in position with the principal symmetry axes, and each is called an *a* axis, as in the holohedral division.

### Orienting Crystals.

Pentagonal hemihedral crystals are oriented in exactly the same way as holohedral ones (see p. 19).

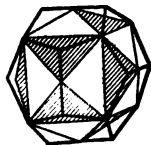


FIG. 19. — Pentagonal dodecahedron containing the form from which it is derived. The suppressed faces are shaded.

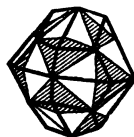


FIG. 20. — Diploid containing the form from which it is derived. The suppressed faces are shaded.

**Pentagonal Hemihedral Isometric Forms Tabulated.**

Name.	Symbol.	Number of faces.	Form from which derived.
Pentagonal dodecahedron } (Fig. 19).....	$\frac{a : ma : \infty a}{2}$	12	tetrahexahedron
Diploid (Fig. 20).....	$\frac{a : ma : na}{2}$	24	hexoctahedron
Octahedron (Fig. 4).....	$\frac{a : a : a}{2}$	8	octahedron
Dodecahedron (Fig. 6).....	$\frac{a : a : \infty a}{2}$	12	dodecahedron
Hexahedron (cube) (Fig. 8)...	$\frac{a : \infty a : \infty a}{2}$	6	hexahedron (cube)
Trapezohedron (Fig. 7).....	$\frac{a : ma : ma}{2}$	24	trapezohedron
Trisectahedron (Fig. 5).....	$\frac{a : a : ma}{2}$	24	trisectahedron

**Synonyms for the Names of the Pentagonal Hemihedral Isometric Forms.**

Pentagonal dodecahedron — pyritohedron.

Diploid — didodecahedron.

**Method of Determining Pentagonal Hemihedral Isometric Forms by the Use of Symbols.**

After properly orienting the crystal in the manner already described the octahedron, dodecahedron, cube, trapezohedron, and trisectahedron may be identified easily by applying the rules already given for the determination of holohedral forms of the same name. The other two forms may be recognized by determining the symbols of any face in the manner described in the discussion of the holohedral forms, dividing this symbol by 2, and then ascertaining from the table the name of the form possessing this symbol.

**Suggestions for Attaining Facility in the Determination of the Forms.**

Orient the crystal and determine which of the following descriptions (which should be learned at once) apply to the face or faces of different shape or size seen. It is unnecessary to distinguish between positive and negative forms in this division. It is assumed that the student is already familiar with the rules for recognizing those forms identical in shape with the holohedral ones (see p. 22).

*Pentagonal dodecahedron:* A face parallel to the right and left axis, and sloping down toward the observer at a relatively gentle angle — less than  $45^\circ$  from the horizontal. The angle which this face makes with a horizontal plane is all that distinguishes it from the face of a dodecahedron with which it may most easily be confused.

If after orienting a crystal a prominent face is found sloping *steeply* down toward the observer — over  $45^\circ$  from the horizontal, rotate the crystal  $90^\circ$  to right or left around the vertical axis before applying the rule just given.

*Diploid:* Three faces lying wholly within the octant, so arranged that none of the edges formed by the intersection of the faces in the unmodified form point directly toward the vertical axis. This applies either to edges below or above the center of the octant. It is useful to remember, further, that edges formed by the intersection of a diploid face with an octahedron face, either below or above the center of the octant, are *never horizontal*; while a trapezohedron face does intersect an octahedron *above* the center on the octant in a *horizontal edge*;

and a trisoctahedron face intersects an octahedron face *below* the center of the octant in a horizontal edge. It should be noted further that trapezohedron faces intersect cube faces in edges which make right-angles with each other, while similar edges formed by the intersection of diploid and cube faces are never at right-angles. These statements should serve to distinguish the diploid from either the trapezohedron or trisoctahedron with which it is most easily confused.

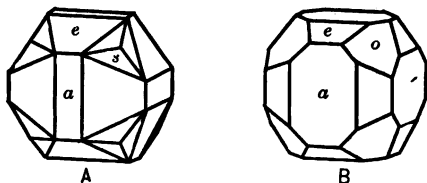


FIG. 21. — Pentagonal hemihedral isometric crystals.

A: Cube (*a*), pentagonal dodecahedron (*e*), and diploid (*s*).

B: Cube (*a*), octahedron (*o*), and pentagonal dodecahedron (*e*).

### Application to the Law Governing Combination of Forms.

The law already stated (see p. 36) governing the combination of forms should not be forgotten when naming the forms on a pentagonal hemihedral crystal. One of the commonest mistakes made in determining crystal forms is to mention two or more forms which cannot possibly occur together on a crystal, as, for instance, a tetrahexahedron and a pentagonal dodecahedron. Any form in the pentagonal hemihedral division may be combined with

any other form in the same division, but no form in the pentagonal hemihedral division may be combined with any form in the tetrahedral hemihedral or holohedral divisions unless that form occurs also in those divisions. The student is very apt to make the mistake mentioned unless he can reproduce easily from memory the following table:

Holohedral forms.	Corresponding tetrahedral hemihedral forms.	Corresponding pentagonal hemihedral forms.
Octahedron . . . . .	<i>tetrahedron</i>	octahedron
Trapezohedron . . .	<i>trigonal tristetrahedron</i>	trapezohedron
Trisoctahedron . . .	<i>tetragonal tristetrahedron</i>	trisoctahedron
Hexoctahedron . . .	<i>hexetetrahedron</i>	<i>diploid</i>
Tetrahexahedron .	<i>tetrahexahedron</i>	<i>pentagonal dodecahedron</i>
Dodecahedron . . .	dodecahedron	dodecahedron
Cube . . . . .	cube	cube

It will be noted from the above table that the cube and dodecahedron occur in all three of the divisions already discussed, and may, therefore, be combined with any other forms in these divisions.

Further, it will be seen that the octahedron, trapezohedron, trisoctahedron, and tetrahexahedron occur unchanged in name or shape in two of the divisions; while the hexoctahedron occurs only as a holohedral form.

### GYROIDAL HEMIHEDRAL DIVISION

Gyroidal hemihedral isometric forms may be conceived to be developed by dividing each holohedral form by both the three principal and the six secondary symmetry planes into forty-eight parts, then suppressing all faces lying wholly within

alternate parts thus obtained, and extending all the remaining faces until they meet in edges or corners.

As the hexoctahedron is the only isometric form with forty-eight faces, it is evident that a hexoctahedron face is the only one that can lie wholly within one of the parts obtained by dividing an isometric crystal in the manner just specified. The hexoctahedron is, then, the only isometric form from which a gyroidal hemihedral form differing from the holohedral one in shape and name can be derived. This new form is called the pentagonal icositetrahedron (Fig. 22). This form may be either right- or left-handed, but gyroidal hemihedral forms are so rare and unimportant that further discussion of them seems unnecessary.

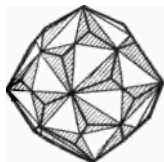


FIG. 22. — Pentagonal icositetrahedron containing the form from which it is derived. The suppressed faces are shaded.

## PENTAGONAL TETARTOEDRAL DIVISION

Pentagonal tetartohedral isometric forms may be conceived to be developed by the simultaneous application of any two hemihedrisms, according to the principles outlined in the discussion of the trapezohedral tetartohedral hexagonal division (see p. 72).

The only holohedral form which yields a tetartohedral form of different shape and name is the hexoctahedron, and the form derived from it is called a tetartohedral pentagonal dodecahedron, tetartohexoctahedron, or tetartoid (Fig. 23).

Both + and -, right- and left-handed tetartoids are distinguishable, but tetartohedral isometric crystals are so rare that further discussion of them seems unnecessary.

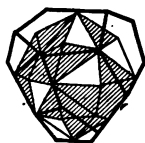


FIG. 23. — Tetartoid containing the form from which it is derived. The suppressed faces are shaded.

**Table of Isometric Symbols Used by Various Authorities.**

	Weiss.	Naumann.	Dana.	Miller.
Octahedron.....	$a : a : a$	O	1	(111)
Trisoctahedron .....	$a : a : ma$	$mO$	$m$	( $hkl$ )
Dodecahedron.....	$a : a : \infty a$	$\infty O$	$i$	(110)
Trapezohedron.....	$a : ma : ma$	$mOm$	$m-m$	( $hll$ )
Hexahedron (cube)....	$a : \infty a : \infty a$	$\infty O \infty$	$i-i$	(100)
Hexoctahedron.....	$a : ma : na$	$mOn$	$m-n$	( $hkl$ )
Tetrahexahedron.....	$a : ma : \infty a$	$\infty On$	$i-n$	( $hko$ )

Weiss, Naumann, and Dana divide the holohedral symbols by 2 and by 4 when referring to hemihedral and tetartohedral forms, respectively. Miller prefixes various Greek letters when forming the symbols of hemihedral and tetartohedral forms.



# CHAPTER III

## HEXAGONAL SYSTEM

### HOLOHEDRAL DIVISION

#### **Symmetry.**

The holohedral division of the hexagonal system is characterized by the presence of one principal and six secondary symmetry planes which lie at right angles to the principal symmetry plane. The secondary symmetry planes are arranged in two groups each of which contains three planes. The planes of each group intersect each other at angles of  $90^\circ$  and  $120^\circ$ , and are interchangeable; while the planes of one group are non-interchangeable with those of the other group which they intersect at angles of  $30^\circ$ ,  $90^\circ$ , or  $150^\circ$ .

#### **Selection, Position, and Designation of the Crystal Axes.**

The principal symmetry axis is chosen as one of the crystal axes, is held vertically, and is called the *c* axis. *Three* other crystal axes are so selected as to coincide with either group of interchangeable secondary symmetry axes. One is held horizontally from right to left. The other two will, then, be horizontal, but will make angles of  $60^\circ$  with each other as well as with the right and left axis (see Fig. 24). Since all three horizontal axes are interchangeable, they are all called *a* axes. None of the

horizontal axes is interchangeable with the vertical axis.

This is the only system in which more than three crystal axes are used. While it would be possible to determine the holohedral forms by the use of three

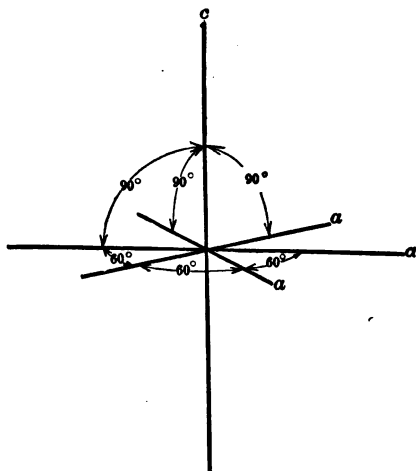


FIG. 24. — Crystal axes of the hexagonal system.

non-interchangeable axes intersecting at right angles, as in the orthorhombic system (see p. 103), this would make it necessary to attach different names to faces identically of the same shape and size, and would in no way suggest the six- or three-fold arrangement of faces which distinguishes this system. It would further necessitate the devising of new rules for developing hemihedral and tetartohedral forms; and would lead to so many difficulties that it is far simpler to use the three interchangeable horizontal axes than two non-interchangeable ones.

**Orienting Crystals.**

Holohedral hexagonal forms are oriented by holding the principal symmetry plane horizontally, and either set of interchangeable secondary symmetry planes in such a way that one of the planes will extend vertically from right to left. The crystal axes will then extend in the proper directions.

**The Law of Rationality or Irrationality of Ratios Between Unit Axial Lengths.**

The ratio between two unit axial lengths on non-interchangeable axes is always an irrational quantity; while the ratio between the unit axial lengths on interchangeable axes is not only a rational quantity, but equals unity.

The law just stated, which applies to all systems, indicates that in the hexagonal system  $a : c$  is always an irrational quantity. If  $a$  be taken as unity, which is always done,  $c$  may be greater or less than unity, but is always an irrational quantity, and is usually given to four decimal places. As an illustration, consider the hexagonal mineral beryl, of which emerald is a variety. The ground-form of this mineral cuts two of the horizontal and the vertical axes at such distances from the origin as will make the ratio between  $a$  and  $c$  as 1 is to 0.4989 (nearly). The unit axial distances of this mineral are, then,  $a = 1$  and  $c = 0.4989$  (nearly). The value of  $c$  differs more or less for all hexagonal minerals. It is, then, a distinguishing characteristic of each hexagonal mineral.

Since  $m$  and  $n$  are always rational quantities (see p. 15), it follows that  $na : c$  and  $a : mc$  are irrational quantities; while  $a : na$  is a rational quantity.

In all systems but the isometric  $m$  may be less than unity; and it is customary to apply this parameter ( $m$ ) to the unit axial length of the *vertical* axis.  $n$  must be greater than unity in the hexagonal and isometric systems only.

### First Order Position Defined.

Forms with faces whose planes cut two horizontal axes equally (at equal finite distances from the origin), and are parallel to the third horizontal axis, are said to be in the first order position.

### Second Order Position Defined.

Forms with faces whose planes cut two of the horizontal axes equally and the third horizontal axis at a distance from the origin which is half that cut off on the other two horizontal axes are said to be in the second order position.

### Third Order Position Defined.

Forms with faces whose planes cut all three horizontal axes unequally are said to be in the third order position.

### Holohedral Hexagonal Forms Tabulated.

Name.	Symbol.	Number of faces.
1st order pyramid (Fig. 25).....	$a : a : \infty a : mc$	12
1st order prism (Fig. 26).....	$a : a : \infty a : \infty c$	6
2nd order pyramid (Fig. 27).....	$2a : a : 2a : mc$	12
2nd order prism (Fig. 28).....	$2a : a : 2a : \infty c$	6
Dihexagonal pyramid (Fig. 29).....	$na : a : pa : mc$	24
Dihexagonal prism (Fig. 30).....	$na : a : pa : \infty c$	12
Basal-pinacoid (Fig. 31).....	$\infty a : \infty a : \infty a : c$	2

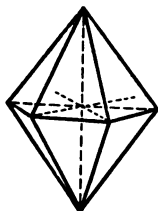


FIG. 25. — 1st order pyramid.

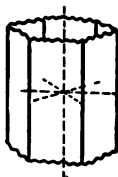


FIG. 26. — 1st order prism.

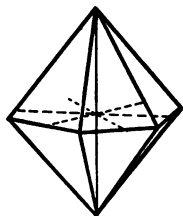


FIG. 27. — 2nd order pyramid.

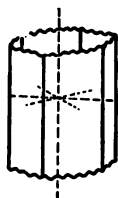


FIG. 28. — 2nd order prism.

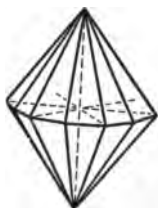


FIG. 29. — Dihexagonal pyramid.

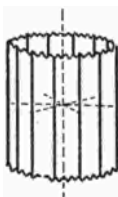


FIG. 30. — Dihexagonal prism.

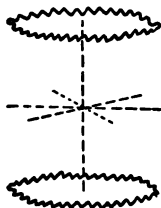


FIG. 31. — Basal pinacoid.

**Synonyms for the Names of the Holohedral Hexagonal Forms.**

1st order pyramid — 1st order bipyramid, or unit pyramid.

1st order prism — unit prism.

2nd order pyramid — 2nd order bipyramid.

2nd order prism — none.

Dihexagonal pyramid — dihexagonal bipyramid.

Dihexagonal prism — none.

Basal-pinacoid — basal plane.

**Method of Determining Holohedral Hexagonal Forms by the Use of Symbols.**

After properly orienting the crystal in the manner already described select any face and ascertain the relative distances at which its plane intersects the four crystal axes, remembering that no face or faces extended can cut the vertical axis at the same distance from the origin as it cuts any of the horizontal axes. If, for instance, it appears that the plane of the face selected intersects all four of the axes, but that the three horizontal axes are all cut at unequal distances from the origin, the symbol of that face (and of the form of which it is a part) is  $na : a : pa : mc$ . By referring to the table of holohedral hexagonal forms (which should be memorized as soon as possible) it is seen that the form is the dihexagonal pyramid. If more than one form is represented on the crystal, each may be determined in the same way.

The parameter  $p$  in the symbol of the dihexagonal pyramid and prism is not an independent variable, but is, in fact, equal to  $\frac{n}{n-1}$ . When  $n$  equals 3,

for instance,  $p$  will equal  $\frac{2}{3}$  or  $1\frac{1}{2}$ . It might be better always to use  $\frac{n}{n-1}$  instead of  $p$ , but, if the equality of the two symbols is always borne in mind, no confusion need result.

It is necessary to write the symbol of hexagonal forms in such a way as will make the second part of each symbol always  $a$  (or  $\infty a$  in the case of the basal-pinacoid). Thus,  $na : a : pa : mc$  is correct, while  $na : pa : a : mc$  is incorrect; and  $a : 2a : 2a : mc$  is not the symbol of the 2nd order pyramid, while  $2a : a : 2a : mc$  is the correct symbol of this form.

#### **Suggestions for Attaining Facility in the Recognition of Forms.**

Orient the crystal and determine which of the following descriptions (which should be learned at once) apply to the faces of different shape or size seen.

*1st order pyramid:* A face sloping down from the vertical axis directly towards the observer.

*1st order prism:* A vertical face extending from right to left.

*2nd order pyramid:* A face sloping down from the vertical axis directly to the right or left.

A 2nd order pyramid differs in no way from a 1st order pyramid excepting in position with respect to the horizontal crystal axes; and a twelve-faced pyramid may be placed in either the 1st or 2nd order position at will. Such a pyramid may, then, be considered either a 1st or a 2nd order pyramid depending upon the set of interchangeable symmetry

axes with which the crystal axes are chosen to coincide. It is only when forms in both the 1st and 2nd order position occur on the same crystal that it is necessary to distinguish between 1st and 2nd order pyramids.

*2nd order prism:* A vertical face extending from front to back.

As is the case with the 2nd order pyramid, a 2nd order prism differs in no way from a 1st order prism

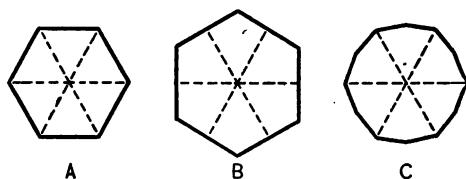


FIG. 32. — Diagrams showing relations of the 1st order (A), 2nd order (B), and dihexagonal (C) pyramids and prisms to the horizontal crystal axes.

excepting in position with respect to the horizontal crystal axes; and all that was said in the preceding section relative to the 2nd order pyramid applies with equal truth to the 2nd order prism.

It is customary to select the horizontal crystal axis in such a way as will place the largest and most prominent twelve-faced pyramid or six-faced prism in the 1st order position.

Pyramids and prisms intersecting in horizontal edges are always of the same order.

*Dihexagonal pyramid:* A face sloping down from the vertical axis in such a way that its plane intersects all three horizontal crystal axes at unequal finite distances from the origin.



*Dihexagonal prism:* A vertical face whose plane intersects all three horizontal crystal axes at unequal finite distances from the origin.

*Basal-pinacoid:* A horizontal face on top of a crystal.

#### Fixed and Variable Forms.

The only fixed holohedral hexagonal forms are the 1st and 2nd order prisms and the basal-pinacoid, and forms derived therefrom.

#### Fixed Angles of the Hexagonal System.

The only fixed angles in this system are those between the fixed forms just mentioned, namely,  $90^\circ$ ,  $120^\circ$  (or  $60^\circ$ ), and  $150^\circ$  (or  $30^\circ$ ).

#### Miscellaneous.

The general statements made in the discussion of the holohedral division of the isometric system

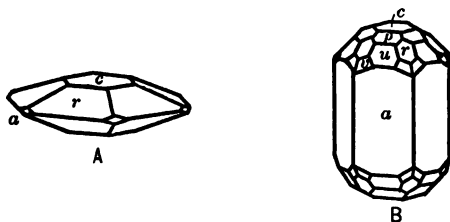


FIG. 33. — Holohedral hexagonal crystals.

A: Basal-pinacoid (*c*), 1st order pyramid (*r*), and 2nd order prism (*a*).

B: Basal-pinacoid (*c*), 1st order prism (*a*), two 1st order pyramids (*p* and *u*), 2nd order pyramid (*r*), and dihexagonal pyramid (*v*).

regarding combination of forms, determination of the number of forms, repetition of forms on a crystal,

and limiting forms applies with equal truth to all the divisions of the hexagonal system. It may be mentioned, however, that repetitions of the same variable form are very common in the hexagonal system, and crystal models showing such repeated forms are not difficult to obtain.

### **RHOMBOHEDRAL HEMIHEDRAL DIVISION**

#### **Development or Derivation of the Forms.**

Rhombohedral hemihedral hexagonal forms may be conceived to be developed by dividing each of the holohedral forms by means of the principal symmetry plane and *the set of interchangeable secondary symmetry planes containing the crystal axes* into twelve parts, or dodecants, then suppressing all faces lying wholly within alternate parts thus obtained, and extending the remaining faces until they meet in edges or corners.

#### **Symmetry.**

Rhombohedral hemihedral forms possess three interchangeable secondary symmetry planes which intersect along a common line at angles of  $60^\circ$  or  $120^\circ$ .

#### **Selection, Position, and Designation of the Crystal Axes.**

The three directions used as crystal axes in the holohedral division are still utilized for the same purpose in the rhombohedral hemihedral division. In other words, the vertical or *c* axis lies at the intersection of the three secondary symmetry planes; while the three interchangeable crystallographic directions used as horizontal or *a* axes are so held

that one of them extends from right to left, and each of them bisects an angle between two of the secondary symmetry planes.

### Orienting Crystals.

Rhombohedral hemihedral forms are oriented by holding a symmetry plane vertically *from front to back*, then rotating the crystal around the axis perpendicular to this plane until two other symmetry planes making angles of  $60^\circ$  to  $120^\circ$  with the plane first mentioned are held vertically. The crystal axes will then extend in the proper directions.

### Rhombohedral Hemihedral Hexagonal Forms Tabulated.

Name.	Symbol.	Number of faces.	Form from which derived.
$\pm$ Rhombohedron (Fig. 34)	$\pm \frac{a : a : \infty a : mc}{2}$	6	1st order pyramid
Hexagonal scalenohedron } (Fig. 35) .....	$\frac{na : a : pa : mc}{2}$	12	{ dihexagonal pyra- mid
1st order prism (Fig. 26)....	$\frac{a : a : \infty a : \infty c}{2}$	6	1st order prism
2nd order pyramid (Fig. 27).	$\frac{2a : a : 2a : mc}{2}$	12	2nd order pyramid
2nd order prism (Fig. 28)...	$\frac{2a : a : 2a : \infty c}{2}$	6	2nd order prism
Dihexagonal prism (Fig. 30)	$\frac{na : a : pa : \infty c}{2}$	12	dihexagonal prism
Basal-pinacoid (Fig. 31)....	$\frac{\infty a : \infty a : \infty a : c}{2}$	2	basal-pinacoid

### Synonyms for the Names of the Rhombohedral Hemihedral Hexagonal Forms.

Rhombohedral — none.

Scalenohedron — none.

**Positive and Negative Forms Distinguished.**

All those forms produced by the suppression of faces lying within the *same set* of alternating dodecants are said to be of the same sign (+ or -). It is customary to consider those forms with faces

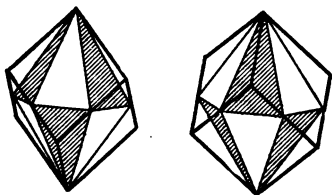


FIG. 34. — Positive (on left) and negative (on right) rhombohedrons containing the forms from which they are derived. The suppressed faces are shaded.

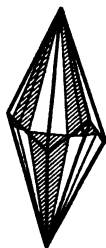


FIG. 35. — Hexagonal scalenohedron containing the form from which it is derived. The suppressed faces are shaded.

largely or entirely included within the upper dodecant directly facing the observer as +, while those with faces in the upper dodecant at the back of the crystal furthest from the observer are -. In reality a + rhombohedron differs in no way from a - rhombohedron excepting in position; and a rhombohedron may be held in either the + or - position at will. It is customary to hold a crystal in such a way as to bring the largest and most prominent rhombohedron face principally or entirely into the upper dodecant facing the observer, which will make this form a + one. It is possible, but unnecessary, to distinguish between + and - hexagonal scalenohedrons.

If the sign of a form is not specifically stated as being  $-$ , it is always assumed that the form is  $+$ .

The forms on a crystal may all be of the same sign, or  $+$  and  $-$  forms may be combined.

**Method of Determining Rhombohedral Hemihedral Hexagonal Forms by the Use of Symbols.**

After properly orienting the crystal all the forms but the rhombohedron and scalenohedron may be easily identified by applying the rules already given for the determination of holohedral forms of the same name. The two hemihedral forms new in shape may be recognized by determining the symbol of any face in the manner described in the discussion of holohedral forms, dividing the symbol by 2, and then ascertaining from the table the name of the form possessing this symbol.

**Suggestions for Attaining Facility in the Recognition of Forms.**

Orient the crystal and determine which of the following descriptions (which should be learned at once) apply to the face or faces of different shape or size seen. It is assumed that the student is already familiar with the rules for recognizing those forms identical in shape with the holohedral ones (see p. 51).

$+$  *Rhombohedron*: A face sloping down from the vertical axis directly toward the observer. A rhombohedron has three faces at each end of the vertical axis so arranged that a face on top is directly above an edge below.

$-$  *Rhombohedron*: A face sloping down from the vertical axis directly away from the observer, at the back of the crystal.

*Hexagonal scalenohedron:* A face, sloping down from the vertical axis in such a way that its plane intersects all three horizontal crystal axes at unequal finite distances from the origin.

The hexagonal scalenohedron is most readily confused with the 2nd order pyramid. To distinguish them, it should be remembered that the upper and lower faces of the latter always intersect in horizontal edges, and that the interfacial angles of the 2nd order pyramid, measured across edges converging towards the vertical axis, are all equal. Neither statement is true as regards the hexagonal scalenohedron.

#### **Rules and Conventions Relating to Rhombohedrons.**

As may be gathered from the statements already made in this volume (see p. 13), the unit rhombohedron in the case of any given mineral species is usually the rhombohedron occurring most commonly on crystals of that mineral. In the case of rhombohedral minerals with a well-developed rhombohedral cleavage (see p. 142), however, it is sometimes found more convenient to select the cleavage rhombohedron as the unit rhombohedron, and to call all distances at which this unit rhombohedron cuts the  $a$  and  $c$  axes the unit axial distances  $a$  and  $c$ .  $a$  is made equal to unity, and  $c$  is then some irrational quantity either greater or less than unity. It is customary to designate the unit rhombohedron by the symbol  $R$  which may be  $+$  or  $-$  according to its position on the crystal.

All other rhombohedrons than  $R$  will cut the  $a$  and  $c$  axes at such distances that if  $a$  is made equal

to unity,  $mc$  will be some rational multiple of  $c$ . If  $m$  is equal to 2, the rhombohedron is represented by the symbol  $2R$ , either  $+$  or  $-$ ; while if  $m$  is equal to  $\frac{1}{2}$ , the rhombohedron is represented by the symbol  $\frac{1}{2}R$ , either  $+$  or  $-$ . Similarly, a rhombohedron intersecting the vertical axis at  $3c$  may be represented by the symbol  $3R$ , etc.

It may be readily proved geometrically (although to offer such a proof is beyond the scope of this work) that any rhombohedron which truncates the edges of another rhombohedron will intersect the vertical axis at one-half the  $c$  value of the truncated rhombohedron and will be of opposite sign. In other words,  $+R$  may have its edges truncated by  $-\frac{1}{2}R$ ;  $-\frac{1}{2}R$  may have its edges truncated by  $+\frac{1}{4}R$ , etc. Stated differently,  $-\frac{1}{2}R$  will truncate the edges of  $+R$ ; or  $-2R$  will truncate the edges of  $+4R$ .

From what has been said it is evident that a  $+$  rhombohedron always truncates a  $-$  rhombohedron or vice versa. In order to ascertain whether one rhombohedron is truncating another, it is only necessary to determine whether one rhombohedron intersects the other in parallel edges. If a rhombohedron is intersected by other rhombohedron faces of opposite sign so as to produce parallel edges, the former is truncating the latter. Fig. 36 illustrates a crystal viewed from above that shows  $+R$ ,  $-\frac{1}{2}R$ ,

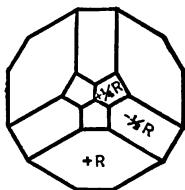


FIG. 36. — View from above of a unit rhombohedron, with its edges truncated by  $-\frac{1}{2}R$ , and the edges of the latter truncated by  $+\frac{1}{4}R$ .

and  $+\frac{1}{4}R$ . If the rhombohedron represented in the case just mentioned as  $-\frac{1}{2}R$  be taken as the unit rhombohedron,  $+R$ , the other rhombohedrons shown will be  $-2R$  and  $-\frac{1}{2}R$ , respectively.

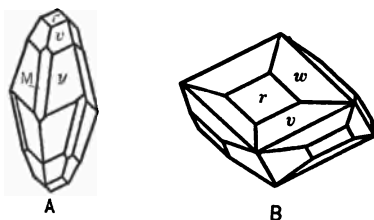


FIG. 37. — Rhombohedral hemihedral hexagonal crystals.

A: Two  $+$  rhombohedrons ( $r$  and  $M$ ) and two scalenohedrons ( $y$  and  $v$ ).

B:  $+$  rhombohedron ( $r$ ) and two scalenohedrons ( $w$  and  $v$ ).

### PYRAMIDAL HEMIHEDRAL DIVISION

#### Development or Derivation of the Forms.

Pyramidal hemihedral hexagonal forms may be conceived to be developed by dividing each of the holohedral forms by means of all six secondary symmetry planes into twelve parts, then suppressing all faces lying wholly within alternate parts thus obtained, and extending the remaining faces until they meet in edges or corners.

#### Symmetry.

Pyramidal hemihedral forms possess only one symmetry plane which is in the position of the principal symmetry plane existing in the holohedral division. It is, however, in the pyramidal hemihedral division a secondary rather than a principal



symmetry plane since there are no interchangeable symmetry planes perpendicular to it.

Pyramidal hemihedral hexagonal forms are, then, characterized by the presence of one secondary symmetry plane, and a general six-fold arrangement of faces.

#### **Selection, Position, and Designation of the Crystal Axes.**

The vertical or *c* crystal axis is made to coincide with the secondary symmetry axis. Three interchangeable horizontal axes parallel to prominent crystallographic directions at angles of  $60^\circ$  or  $120^\circ$  to each other are also selected, and one of these is so placed as to extend from right to left. Being interchangeable, all are called *a* axes.

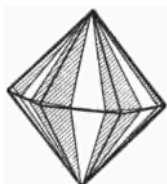


FIG. 38. — 3rd order pyramid containing the form from which it is derived. Suppressed faces are shaded.

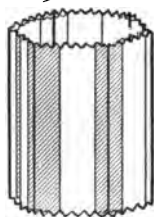


FIG. 39. — 3rd order prism containing the form from which it is derived. Suppressed faces are shaded.

#### **Orienting Crystals.**

The secondary symmetry plane is held horizontally. The crystal is then rotated around the symmetry axis until the most prominent pyramid or prism lies in the first order position. The crystal axes will then extend in the proper directions.

**Pyramidal Hemihedral Hexagonal Forms Tabulated.**

Name.	Symbol.	Number of faces.	Form from which derived.
3rd order pyramid (Fig. 38).	$\frac{na : a : pa : mc}{2}$	12	dihexagonal pyramid
3rd order prism (Fig. 39)....	$\frac{na : a : pa : \infty c}{2}$	6	dihexagonal prism
1st order pyramid (Fig. 25).	$\frac{a : a : \infty a : mc}{2}$	12	1st order pyramid
1st order prism (Fig. 26)....	$\frac{a : a : \infty a : \infty c}{2}$	6	1st order prism
2nd order pyramid (Fig. 27)	$\frac{2a : a : 2a : mc}{2}$	12	2nd order pyramid
2nd order prism (Fig. 28)...	$\frac{2a : a : 2a : \infty c}{2}$	6	2nd order prism
Basal-pinacoid (Fig. 31).....	$\frac{\infty a : \infty a : \infty a : c}{2}$	2	basal-pinacoid

**Synonyms for the Names of the Pyramidal Hemihedral Hexagonal Forms.**

3rd order pyramid — 3rd order bipyramid.

3rd order prism — none.

**Method of Determining Pyramidal Hemihedral Hexagonal Forms by the Use of Symbols.**

After properly orienting the crystal in the manner already described all the forms but the 3rd order pyramid and prism may be identified easily by applying the rules already given for the determination of holohedral forms of the same name. 3rd order pyramids and prisms may be recognized by determining the symbol of any face in the manner already described in the discussion of holohedral forms, dividing this symbol by 2, and then ascertaining from the table the name of the form possessing this symbol.

### Suggestions for Attaining Facility in the Recognition of Forms.

Orient the crystal and determine which of the following descriptions (which should be learned at once) apply to the face or faces of different shape or size seen. It is possible, but unnecessary, to distinguish between + and - forms in this division. It is assumed that the student is already familiar with the rules for recognizing those forms identical in shape and position with the holohedral ones (see p. 51).

*3rd order pyramid:* A face sloping down from the vertical axis so that its plane intersects all three horizontal crystal axes at unequal finite distances from the origin.

The 3rd order pyramid differs in no way from the 1st or 2nd order pyramid excepting in position with respect to the horizontal crystal axes. All three types of 12-faced pyramids may have the same appearance; and any such pyramid may be held at will as a 1st, 2nd, or 3rd order pyramid. The 3rd order pyramid is skewed or twisted through

a small angle (less than  $30^\circ$ ) either to the right or left away from the position of the 1st or 2nd order pyramid. Fig. 40 shows how the horizontal axes are cut by 1st, 2nd, and 3rd order pyramids and prisms.

*3rd order prism:* A vertical face whose plane inter-

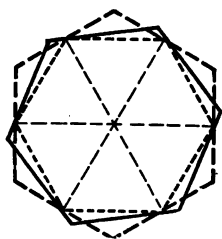


FIG. 40. — Diagram showing the relations of the 1st order (dotted lines), 2nd order (broken lines), and 3rd order (solid lines) pyramids and prisms to the horizontal crystal axes.

sects the three horizontal crystal axes at unequal finite distances from the origin.

All that was said in the preceding section relative to the 3rd order pyramid applies with equal truth to the 3rd order prism.

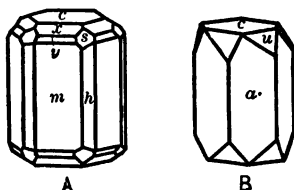


FIG. 41. — Pyramidal hemihedral hexagonal crystals.

A: Basal-pinacoid ( $c$ ), 1st order prism ( $m$ ), two 1st order pyramids ( $x$  and  $y$ ), 2nd order pyramid ( $s$ ), and 3rd order prism ( $h$ ).

B: Basal-pinacoid ( $c$ ), 2nd order prism ( $a$ ), and 3rd order pyramid ( $u$ ).

### TRIGONAL HEMIHEDRAL DIVISION

#### Development or Derivation of the Forms.

Trigonal hemihedral hexagonal forms may be conceived to be developed by dividing each of the holohedral forms by means of the three secondary symmetry planes containing the horizontal crystal axes into six parts, then suppressing all faces lying wholly within alternate parts thus obtained, and extending the remaining faces until they meet in edges or corners.

#### Symmetry.

The trigonal hemihedral division of the hexagonal system is characterized by the presence of one principal and three interchangeable secondary symmetry planes which lie at right angles to the principal

symmetry plane. The interchangeable symmetry planes make angles of 60° or 120° with each other.

**Selection, Position, and Designation of the Crystal Axes.**

The principal symmetry axis is chosen as the vertical or *c* crystal axis; while three interchangeable horizontal directions, each of which bisects the angle between two secondary symmetry planes, constitute the horizontal or *a* axes. One of these is so held as to extend from right to left.

**Orienting Crystals.**

Trigonal hemihedral forms are oriented by holding the principal symmetry plane horizontally, and one secondary symmetry plane vertically and extending from front to back. The crystal axes will then extend in the proper direction.

**Trigonal Hemihedral Hexagonal Forms Tabulated.**

Name.	Symbol.	Number of faces.	Form from which derived.
± 1st order trigonal pyramid (Fig. 42).....	$\pm \frac{a : a : \infty a : mc}{2}$	6	1st order pyramid
± 1st order trigonal prism (Fig. 43).....	$\pm \frac{a : a : \infty a : \infty c}{2}$	3	1st order prism
Ditrigonal pyramid (Fig. 44).....	$\frac{na : a : pa : mc}{2}$	12	dihexagonal pyramid
Ditrigonal prism (Fig. 45).....	$\frac{na : a : pa : \infty c}{2}$	6	dihexagonal prism
2nd order pyramid (Fig. 27)	$\frac{2a : a : 2a : mc}{2}$	12	2nd order pyramid
2nd order prism (Fig. 28).....	$\frac{2a : a : 2a : \infty c}{2}$	6	2nd order prism
Basal-pinacoid (Fig. 31).....	$\frac{\infty a : \infty a : \infty a : c}{2}$	2	basal-pinacoid

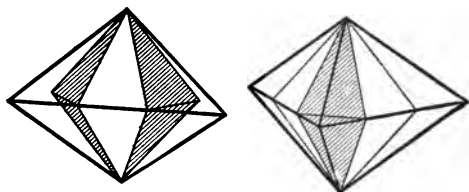


FIG. 42. — Positive (on left) and negative (on right) 1st order trigonal pyramids containing the forms from which they are derived. The suppressed faces are shaded.

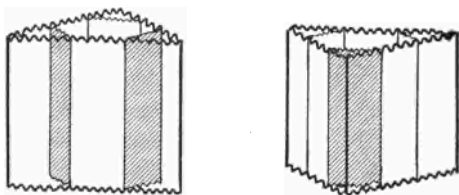


FIG. 43. — Positive (on left) and negative (on right) 1st order trigonal prisms containing the forms from which they are derived. The suppressed faces are shaded.

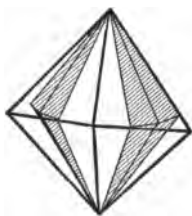


FIG. 44. — Ditrigonal pyramid containing the form from which it is derived. The suppressed faces are shaded.

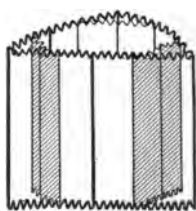


FIG. 45. — Ditrigonal prism containing the form from which it is derived. The suppressed faces are shaded.

**Synonyms for the Names of the Trigonal Hemihedral Hexagonal Forms.**

1st order trigonal pyramid — trigonal bipyramid of the 1st order.

Ditrigonal pyramid — ditrigonal bipyramid.

**Positive and Negative Forms Distinguished.**

All those forms produced by the suppression of faces lying within the same set of alternating dodecants are said to be of the same sign (+ or -). It is possible, but unnecessary, to distinguish between + and - ditrigonal pyramids and prisms. It is customary to consider a trigonal prism or pyramid with a face or faces extending from right to left between the vertical axis and the observer as +, while one with such a face or faces back of the vertical axis is -. In reality, a + trigonal pyramid differs in no way from a - trigonal pyramid excepting in position; and a trigonal pyramid may be held in either the + or - position at will. The same statements hold as regards the trigonal prism. Convention requires that the largest and most prominent trigonal pyramid or prism should be held in such a way as to bring it into the + position.

All the other statements regarding + and - forms made in the discussion of the rhombohedral hemihedral division (see p. 57) apply with equal truth to the division under consideration.

**Method of Determining Trigonal Hemihedral Hexagonal Forms by the Use of Symbols.**

After properly orienting the crystal in the manner already described the 2nd order pyramid and prism

and the basal-pinacoid may be identified easily by applying the rules already given for the determination of holohedral forms of the same name.

The four hemihedral forms differing in shape from the holohedral ones from which they were derived may be recognized by determining the symbol of any face in the manner described in the discussion of holohedral forms, dividing this symbol by 2, and then ascertaining from the table the name of the form possessing this symbol.

#### **Suggestions for Attaining Facility in the Recognition of Forms.**

Orient the crystal and determine which of the following descriptions (which should be learned at once) apply to the face or faces of different shape or size seen. It is assumed that the student is already familiar with the rules for recognizing those forms identical in shape with the holohedral ones (see p. 51).

+ *1st order trigonal pyramid*: A face sloping down from the vertical axis directly toward the observer. This face occupies exactly the same position as that of a + rhombohedron. However, a 1st order trigonal pyramid differs from a rhombohedron in that the three faces at one end of the vertical axis intersect those at the other end in edges which are horizontal.

- *1st order trigonal pyramid*: A face sloping down from the vertical axis directly away from the observer at the back of the crystal. This face occupies exactly the same position as that of a - rhombohedron.



+ *1st order trigonal prism*: A vertical face extending directly from right to left between the vertical axis and the observer.

— *1st order trigonal prism*: A vertical face extending directly from right to left at the back of the crystal.

*Ditrigonal pyramid*: A face sloping down from the vertical axis in such a way that its plane intersects the three horizontal crystal axes at unequal finite distances from the origin. The six faces at each end of the vertical axis occupy exactly the same positions as the six faces making up half of a scalenohedron, but may be distinguished from scalenohedron faces by the fact that the faces at opposite ends of the vertical axis intersect in edges that are horizontal.

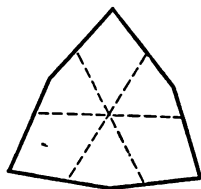


FIG. 46. — Diagram showing the relation of the faces of the trigonal hemihedral ditrigonal pyramid and prism to the horizontal crystal axes. (Compare with Fig. 54.)

*Ditrigonal prism*: A vertical face whose plane intersects all three horizontal crystal axes at unequal finite distances from the origin.

### Hemimorphism.

A hemimorphic crystal, as already stated (p. 17), is one in which the law of axes (see p. 16) is violated so far as one crystal axis is concerned. In other words, on a hemimorphic crystal the opposite ends of one crystal axis are not cut by the same number of similarly placed faces. For instance, there may be one or more pyramids on one end of a crystal axis,

and only a basal pinacoid on the other; or the forms at both ends of an axis may have the same names, but different slopes.

Theoretically, hemimorphic forms may occur in all divisions of the hexagonal system, but they are relatively unimportant on any kind of crystals already discussed excepting trigonal hemihedral hexagonal ones.

#### **Naming Hemimorphic Forms.**

It is customary to hold the axis whose ends are treated differently vertically. After properly orienting the crystal the forms on the upper end of the crystal are given first, then the crystal is turned upside down, and those on the other end are named. Forms common to both ends, like prisms and pinacoids (other than the basal pinacoid), are mentioned but once.

In writing out the names of the forms on a hemimorphic crystal it is customary to separate the names of the forms on the differing ends of the crystal by means of a horizontal line.

#### **Importance of Hemimorphism in the Trigonal Hemihedral Hexagonal Division.**

With one possible exception, all natural minerals crystallizing in this division of the hexagonal system are hemimorphic, that is, the opposite ends of their vertical axes are not intersected by the same number of similar faces similarly placed. This eliminates the principal symmetry plane, and gives the trigonal and ditrigonal pyramids the appearance of rhombohedrons and scalenohedrons. That the crystals

resulting are not rhombohedral is, however, usually shown plainly by the presence of a prominent trigonal prism, a form which does not occur in the rhombohedral hemihedral division. This gives trig-

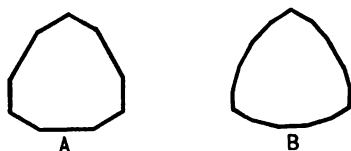


FIG. 47. — Typical horizontal sections of the trigonal hemihedral mineral tourmaline.

onal hemihedral crystals cross-sections which are either triangular or (more commonly) spherical-triangular. Fig. 47 shows two typical cross-sections of the mineral tourmaline which is the commonest species crystallizing in this division of the system.

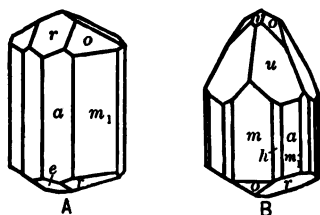


FIG. 48. — Trigonal hemihedral hexagonal crystals (hemimorphic).

A: + and -1st order trigonal pyramids ( $r$  and  $o$ ), -1st order trigonal prism ( $m_1$ ), and 2nd order prism ( $a$ ). On other end: + and -1st order trigonal pyramids ( $r$  and  $e$ ).

B: + and -1st order trigonal pyramids ( $r$  and  $o$ ), + and -1st order trigonal prisms ( $m$  and  $m_1$ ), ditrigonal pyramid ( $u$ ), ditrigonal prism ( $h$ ), and 2nd order prism ( $a$ ). On other end: + and -1st order trigonal pyramids ( $r$  and  $o$ ).

### TRAPEZOHEDRAL HEMIHEDRAL DIVISION

Trapezohedral hemihedral forms may be conceived to be developed by dividing each holohedral form by the principal and all the secondary symmetry planes into 24 parts, then suppressing all faces lying wholly within alternate parts thus obtained, and extending all the remaining faces until they meet in edges or corners.

As the dihexagonal pyramid is the only hexagonal form with 24 faces, it is evident that a dihexagonal pyramid face is the only one that can lie wholly within one of the parts obtained by dividing a hexagonal crystal in the manner just specified. The dihexagonal pyramid is, then, the only hexagonal form from which a trapezohedral hemihedral form differ-

ing from the holohedral one in shape and name can be derived. This new form is called the hexagonal trapezohedron (Fig. 49). This form may be either right or left-handed, but, since no mineral is known to crystallize in this division, its further discussion seems unnecessary.

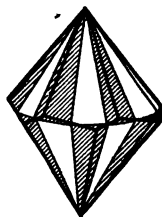


FIG. 49. — Hexagonal trapezohedron containing the form from which it is derived. The suppressed faces are shaded.

### TRAPEZOHEDRAL TETARTOHEDRAL DIVISION

#### Development or Derivation of the Forms.

Trapezohedral tetartohedral hexagonal forms may be conceived to be developed by the simultaneous application of the rhombohedral and trapezohedral hemihedrisms. In other words, a holohedral form is first divided into dodecant by means of the principal symmetry plane and the three secondary symmetry planes containing the crystal axes, as in the development of rhombohedral hemihedral forms; and faces or portions of faces lying within alter-

nating dodecants are marked tentatively as subject to suppression. The holohedral form is then divided by means of the principal and all of the secondary symmetry planes into twenty-four parts, as in the development of trapezohedral hemihedral forms; and faces or portions of faces lying within alternating parts thus obtained are marked tentatively as subject to suppression. If, after this has been done, it is found that any crystal face has been marked in such a way as to indicate that all portions of it are tentatively subject to suppression, that

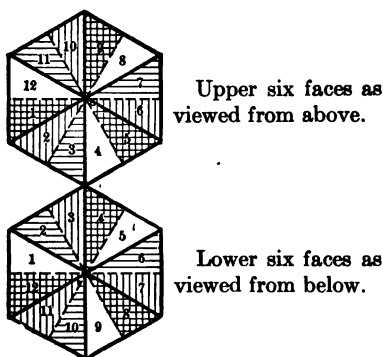


FIG. 50. — Diagram to illustrate the development of the 2nd order trigonal pyramid from the 2nd order pyramid as explained in the text.

crystal face is suppressed; but, if all or any portion of a crystal face remains unmarked as subject to suppression, that face is extended until it meets other similar faces in edges or corners.

As an illustration of the process just outlined, consider a 2nd order pyramid (see Fig. 50). If this form is divided by means of the principal symmetry

plane and the secondary symmetry planes containing the crystal axes, and faces or parts of faces lying within alternating dodecants thus obtained are marked tentatively as subject to suppression, parts of faces 1 and 2, 5 and 6, and 9 and 10 on top of the crystal; and 3 and 4, 7 and 8, and 11 and 12 on the other end should be so marked, as indicated by the vertically hatched portions on Fig. 50. If, then, the form be divided by means of the principal symmetry plane and all six secondary symmetry planes into twenty-four parts, and faces or parts of faces lying within alternating parts thus obtained be marked tentatively as subject to suppression, the parts of the faces so marked will be those num-

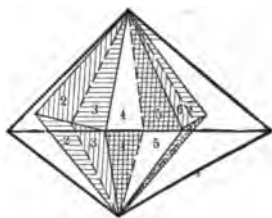


FIG. 51. — 2nd order trigonal pyramid containing the form from which it is derived. Suppressed faces are shaded.

bered 1, 3, 5, 7, 9, and 11 on top of the crystal, and 2, 4, 6, 8, 10, and 12 on the bottom, as indicated by the horizontally hatched portions in Fig. 50. This leaves the half-faces 4, 8, and 12, on top, and the half-faces 1, 5, and 9, on the other end of the crystal unhatched, while all the remaining faces are completely hatched. If, then, we extend the faces partially unhatched until they meet in edges or corners as illustrated by Fig. 51, we shall obtain the trapezohedral tetartohedral derivative of the second order pyramid, namely, the 2nd order trigonal pyramid. By applying this method to the other holohedral forms, their trapezohedral tetartohedral derivatives may be ascertained.

**Symmetry.**

Trapezohedral tetartohedral forms possess no symmetry planes whatever, but show a three-fold or six-fold arrangement of faces.

**Selection, Position, and Designation of the Crystal Axes.**

The four directions used as crystal axes in the holohedral division are still utilized for the same purpose in the trapezohedral tetartohedral division. In other words, one vertical or *c* axis and three interchangeable horizontal or *a* axes intersecting at angles of  $60^\circ$  or  $120^\circ$  are utilized. One of the latter is held from right to left.

**Orienting Crystals.**

The absence of all symmetry planes, and the presence of two sets of prominent interchangeable crystallographic directions which may be so placed as to occupy the position of the horizontal crystal axes makes it impossible to give any rules for orienting trapezohedral tetartohedral crystals based entirely on symmetry planes or crystallographic directions.

Since quartz is the only mineral which occurs at all commonly in recognizable trapezohedral tetartohedral crystals, it seems best to suggest rules for orientation applicable especially to that mineral. These are as follows:

On most crystals one crystallographic direction emerging on the surface of the crystal at a corner formed by the intersection of three or six faces making equal angles with each other is usually very

prominent. This is selected as the vertical or *c* axis, and is not interchangeable with any other crystallographic direction. The crystal is then rotated around the vertical axis until prominent prism faces occupy the 1st order position; or, if a prominent prism is lacking, prominent pyramidal faces are placed in the 1st order position. The three interchangeable horizontal crystal axes will then extend in the proper directions.

**Trapezohedral Tetartohedral Hexagonal Forms Tabulated.**

Name.	Symbol.	Number of faces.	Form from which derived.
$\pm$ Rhombohedron (Fig. 34)	$\pm \frac{a : a : \infty a : mc}{4}$	6	1st order pyramid
$\pm$ 2nd order trigonal pyramid (Fig. 51)	$\pm \frac{2a : a : 2a : mc}{4}$	6	2nd order pyramid
$\pm$ 2nd order trigonal prism (Fig. 52)	$\pm \frac{2a : a : 2a : \infty c}{4}$	3	2nd order prism
Trigonal trapezohedron (Fig. 53)	$\frac{na : a : pa : mc}{4}$	6	dihexagonal pyramid
Ditrigonal prism (Fig. 54)	$\frac{na : a : pa : \infty c}{4}$	6	dihexagonal prism
1st order prism (Fig. 26)	$\frac{a : a : \infty a : \infty c}{4}$	6	1st order prism
Basal-pinacoid (Fig. 31)	$\frac{\infty a : \infty a : \infty a : c}{4}$	2	basal-pinacoid

**Synonyms for the Names of the Trapezohedral Tetartohedral Hexagonal Forms.**

2nd order trigonal pyramid — trigonal bipyramid of the 2nd order.

2nd order trigonal prism — unsymmetrical trigonal prism.



Trigonal trapezohedron — quadrilateral trapezohedron.

**Positive and Negative Forms Distinguished.**

It is possible to distinguish between + and - variations of each of the trapezohedral tetartohedral forms which differ in shape from the holohedral ones

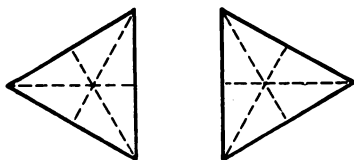


FIG. 52. — Diagrams showing relations of the positive (on left) and negative (on right) 2nd order trigonal pyramid and prism to the horizontal crystal axes.

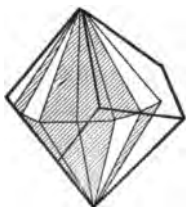


FIG. 53. — Trigonal trapezohedron containing the form from which it is derived. The suppressed faces are shaded.

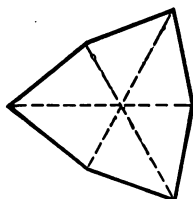


FIG. 54. — Diagram showing the relation of the tetartohedral ditrigonal prism to the horizontal crystal axes.

from which they are derived. It is, however, unnecessary to differentiate between + and - trigonal trapezohedrons and ditrigonal prisms.

+ and - rhombohedrons are distinguished in exactly the same way as are + and - rhombohe-

drons in the rhombohedral hemihedral division (see p. 56).

It is customary to call those trigonal prisms and pyramids + which have a face or faces extending directly from front to back at the *right* of the vertical axes; while those with a similar face or faces at the *left* of the vertical axis are called -. See Fig. 52.

### **Symbols of Tetartohedral Forms.**

The symbol of a tetartohedral form in any system is the same as that of the holohedral form from which it is derived excepting that it is written as a fraction with the figure 4 as the denominator. This does not mean that, in the case of the tetartohedral forms, the axes are intersected at one-fourth the holohedral axial lengths, but is merely a conventional method of indicating that the symbol is that of a quarter (tetartohedral) form. The symbol  $\frac{na : a : pa : mc}{4}$  is read *na, a, pa, mc* over 4.

### **Method of Determining Trapezohedral Tetartohedral Hexagonal Forms by the Use of Symbols.**

After properly orienting the crystal the 1st order prism and basal-pinacoid may be identified easily by applying the rules already given for the determination of holohedral forms of the same name. The tetartohedral forms new in shape may be recognized by determining the symbol of any face in the manner described in the discussion of holohedral forms, dividing this symbol by 4, and then ascertaining from the table the name of the form possessing this symbol.

**Suggestions for Attaining Facility in the Recognition of Forms.**

Orient the crystal and determine which of the following descriptions (which should be learned at once) apply to the face or faces of different shape or size seen. It is assumed that the student is already familiar with the rules for recognizing those forms identical in shape with the holohedral ones (see p. 51).

$\pm$  *Rhombohedron*: Since the trapezohedral tetartohedral rhombohedrons differ in no way excepting in internal molecular arrangement from the rhombohedral hemihedral forms of the same name, rules for the recognition of the + and - rhombohedrons given in the description of rhombohedral hemihedral forms (see p. 57) may be used in identifying such forms in this division.

+ *2nd order trigonal pyramid*: A face which slopes down from the vertical axis directly to the right.

The 2nd order trigonal pyramid does not differ in appearance from the 1st order trigonal pyramid occurring in the trigonal hemihedral division, but does differ from the latter in its position with reference to the horizontal crystal axes.

- *2nd order trigonal pyramid*: A face which slopes down from the vertical axis directly to the left.

+ *2nd order trigonal prism*: A vertical face extending from front to back at the right of the vertical axis.

The 2nd order trigonal prism does not differ in appearance from the 1st order trigonal prism occurring in the trigonal hemihedral division, but does

differ from the latter in its position with reference to the horizontal crystal axes.

— *2nd order trigonal prism*: A vertical face extending from front to back at the left of the vertical axis.

*Trigonal trapezohedron*: A face sloping down from the vertical axis in such a way that its plane intersects all three horizontal crystal axes at unequal finite distances from the origin.

It is possible, but not necessary, to distinguish between right- and left-handed trigonal trapezohedrons.

The trigonal trapezohedron, like the 1st and 2nd order trigonal pyramids and the rhombohedron, has three faces at each end of the vertical axis, but the faces on top do not intersect those below in horizontal edges, as is the case with the trigonal pyramid; nor is a face on top directly above an edge below, as is the case with the rhombohedron. The three faces on one end appear, in fact, to have been twisted around the vertical axis through a small angle (less than  $30^\circ$ ) to the right or left, placing them in an unsymmetrical position with reference to those at the other end of the crystal.

The trigonal trapezohedron is most apt to be confused with a 2nd order trigonal pyramid. These may usually be distinguished easily if the following tests are applied:

\ If a vertical plane is passed through an edge between two equally steep 1st order faces, it will bisect the angle between two diverging edges of a 2nd order trigonal pyramid face directly above or below the edge first mentioned. Equally steep 1st order faces in this division of the system are those of the 1st

order prism, and, in the case of quartz, those between the most prominent + and - rhombohedrons.

The statement just made will not be found true where trigonal trapezohedrons lie over or under the edges formed by the intersection of equally steep 1st order faces.

*Ditrigonal prism:* The tetartohedral ditrigonal prism closely resembles the trigonal hemihedral form of the same name (see p. 66), but differs therefrom in that it appears to have a symmetry plane running from right to left (see Fig. 54), while the hemihedral form has a symmetry plane extending from front to back (see Fig. 46).

#### **General Observations.**

It has already been mentioned that quartz is the only common mineral crystallizing in this division of the hexagonal system, and it should be noted that the crystallization of quartz is peculiar in that the most prominent faces are a 1st order prism (sometimes missing) and an equally or unequally developed + and - rhombohedron the faces of which make equal angles with the prism faces. In the absence of other forms, the combination last mentioned appears to be rhombohedral hemihedral, while the first combination appears to be holohedral. The presence of either a trigonal trapezohedron or trigonal pyramid is sufficient to prove the crystal tetartohedral, but these forms are very rare. The trigonal and ditrigonal prisms and basal-pinacoid are almost never found on quartz crystals.

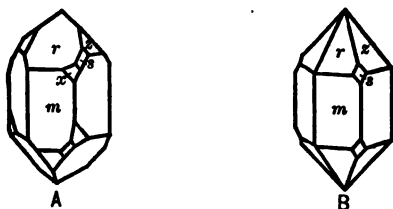


FIG. 55. — Trapezohedral tetartohedral hexagonal crystals.

A: + and - rhombohedrons ( $r$  and  $z$ ), 1st order prism ( $m$ ), - 2nd order trigonal pyramid ( $s$ ), and trigonal trapezohedron ( $x$ ).

B: + and - rhombohedron ( $r$  and  $z$ ) equally developed, 1st order prism ( $m$ ), and - 2nd order trigonal pyramid ( $s$ ).

#### Application of the Law Governing Combination of Forms.

It has already been mentioned that one of the commonest mistakes made in determining crystal forms is the naming of two or more forms which cannot possibly occur on the same crystal since their presence would be in direct violation of the law governing the combination of forms (see p. 36). The student should thoroughly familiarize himself with the table on p. 83 if he wishes to avoid the mistake mentioned.

Inspection of this table will show that the basal-pinacoid is the only form that occurs unchanged in all five of the divisions tabulated. It is, then, the only form that can be combined with any other of the forms in the divisions considered. Further, it should be noticed that the 1st order prism occurs unchanged in all divisions but the trigonal hemihedral, while the 2nd order pyramid and prism occur unchanged in all divisions but the trapezohedral tetartohedral. The forms in the 3rd

Holohedral forms.	Rhombohedral hemi-hedral forms.	Pyramidal hemi-hedral forms.	Trigonal hemihedral forms.	Trapezohedral tetartohedral forms.
1st order pyramid .....	<i>rhombohedron</i>	1st order pyramid	1st order trigonal pyramid	<i>rhombohedron</i>
1st order prism .....	1st order prism	1st order prism	1st order trigonal prism	1st order prism
2nd order pyramid .....	2nd order pyramid	2nd order pyramid	2nd order pyramid	2nd order trigonal pyramid
2nd order prism .....	2nd order prism	2nd order prism	2nd order prism	2nd order trigonal prism
Dihexagonal pyramid ..	<i>hexagonal scalenohedron</i>	3rd order pyramid	ditrigonal pyramid	trigonal trapezohedron
Dihexagonal prism .....	dihexagonal prism	3rd order prism	ditrigonal prism	ditrigonal prism
Basal-pinacoid .....	basal-pinacoid	basal-pinacoid	basal-pinacoid	basal-pinacoid

order position are apt to give the most trouble, since the dihexagonal pyramid yields a form of new name and shape in each of the hemihedral and tetartohedral divisions; while the dihexagonal prism yields a form of new name and shape in all divisions but the rhombohedral hemihedral.

### RHOMBOHEDRAL TETARTOHEDRAL DIVISION

Rhombohedral tetartohedral forms may be conceived to be developed by the simultaneous application of the rhombohedral and pyramidal hemihedrism, according to the principles outlined in the discussion of the trapezohedral tetartohedral hexagonal division (see p. 72). The names of the resulting rhombohedral tetartohedral forms together with their symbols, number of faces, and the name of the corresponding holohedral forms are shown on the following table:

Name.	Symbol.	Number of faces.	Form from which derived.
1st order rhombohedron..	$\frac{a : a : \infty a : mc}{4}$	6	1st order pyramid
2nd order rhombohedron..	$\frac{2a : a : 2a : mc}{4}$	6	2nd order pyramid
3rd order rhombohedron..	$\frac{na : a : pa : mc}{4}$	6	dihexagonal pyramid
3rd order prism.....	$\frac{na : a : pa : \infty c}{4}$	6	dihexagonal prism
1st order prism.....	$\frac{a : a : \infty a : \infty c}{4}$	6	1st order prism
2nd order prism.....	$\frac{2a : a : 2a : \infty c}{4}$	6	2nd order prism
Basal-pinacoid.....	$\frac{\infty a : \infty a : \infty a : c}{4}$	2	basal-pinacoid

The rhombohedral tetartohedral 3rd order prism is exactly like the form of the same name in the pyramidal hemihedral



division (see p. 63). The 1st order rhombohedron is exactly like the rhombohedron occurring in the rhombohedral hemihedral and the trapezohedral tetartohedral divisions; while the 2nd and 3rd order rhombohedrons differ from the 1st order form of the same name only in position with reference to the crystal axes. The former is, of course, in the 2nd order position, while the latter is in the 3rd order position.

Further consideration of this division seems unnecessary since few minerals are rhombohedral tetartohedral, and these are comparatively rare.

**Table of Hexagonal Symbols Used by Various Authorities.**

	Weiss.	Naumann.	Dana.	Miller.
1st order pyramid.....	$a : a : \infty a : mc$	$mP$	$m$	$(M\bar{O}h\bar{i})$
1st order prism.....	$a : a : \infty a : \infty c$	$\infty P$	$I$	$(10\bar{1}0)$
2nd order pyramid.....	$2a : a : 2a : mc$	$mP2$	$m-2$	$(h\bar{h}2h2i)$
2nd order prism.....	$2a : a : 2a : \infty c$	$\infty P2$	$i-2$	$(10\bar{2}0)$
Dihexagonal pyramid.....	$na : a : pa : mc$	$mPn$	$m-n$	$(hk\bar{l}i)$
Dihexagonal prism.....	$na : a : pa : \infty c$	$\infty Pn$	$i-n$	$(hk\bar{l}0)$
Basal-pinacoid.....	$\infty a : \infty a : \infty a : c$	$0P$	$O$	$(0001)$

Weiss, Naumann, and Dana divide the holohedral symbols by 2 and by 4 when referring to hemihedral and tetartohedral forms, respectively. Miller prefixes various Greek letters when forming the symbols of hemihedral and tetartohedral forms.

# CHAPTER IV

## TETRAGONAL SYSTEM

### HOLOHEDRAL DIVISION

#### Symmetry.

The holohedral division of the tetragonal system is characterized by the presence of one principal and four secondary symmetry planes which lie at right angles to the principal symmetry plane. The secondary symmetry planes are arranged in two pairs. The planes of each pair intersect each other at an angle of  $90^\circ$  and are interchangeable; while the planes of one pair are non-interchangeable with those of the other pair which they intersect at an angle of  $45^\circ$ .

#### Selection, Position, and Designation of the Crystal Axes.

The principal symmetry axis is chosen as one of the crystal axes, is held vertically, and is called the *c* axis. Two other crystal axes are so selected as to coincide with one set of interchangeable secondary symmetry axes. One is held horizontally from front

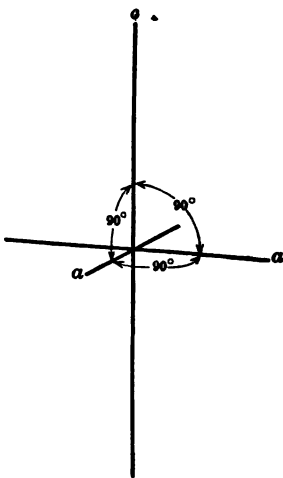


FIG. 56. — Crystal axes of the tetragonal system.

to back, the other horizontally from right to left, and both are called *a* axes, since they are interchangeable. Three crystal axes intersecting at right angles are, then, used in the tetragonal system, as in the isometric, and they are held in the same positions as in the isometric system. The two horizontal axes are interchangeable, but, unlike the conditions in the isometric system, neither is interchangeable with the vertical axis (see Fig. 56).

#### **Orienting Crystals.**

Holohedral tetragonal forms are oriented by holding the principal symmetry plane horizontally, and either set of interchangeable secondary symmetry planes vertically from front to back and from right to left. The crystal axes will then extend in the proper directions.

#### **First Order Position Defined.**

Forms with faces or faces extended that cut the two horizontal crystal axes equally (at equal finite distances from the origin) are said to be in the first order position.

#### **Second Order Position Defined.**

Forms with faces or faces extended parallel to one (and only one) horizontal axis are said to be in the second order position.

#### **Third Order Position Defined.**

Forms with faces or faces extended that cut the two horizontal axes unequally at finite distances are said to be in the third order position.

**Holohedral Tetragonal Forms Tabulated.**

Name.	Symbol.	Number of faces.
1st order pyramid (Fig. 57).....	$a : a : mc$	8
1st order prism (Fig. 58).....	$a : a : \infty c$	4
2nd order pyramid (Fig. 59).....	$a : \infty a : mc$	8
2nd order prism (Fig. 60).....	$a : \infty a : \infty c$	4
Ditetragonal pyramid (Fig. 61).....	$a : na : mc$	16
Ditetragonal prism (Fig. 62).....	$a : na : \infty c$	8
Basal-pinacoid (Fig. 63).....	$\infty a : \infty a : c$	2

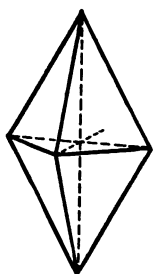


FIG. 57. — 1st order pyramid.

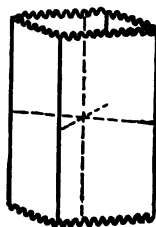


FIG. 58. — 1st order prism.

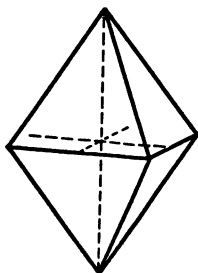


FIG. 59. — 2nd order pyramid.

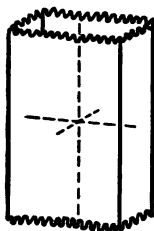


FIG. 60. — 2nd order prism.

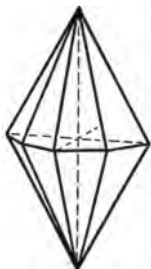


FIG. 61. — Ditetragonal pyramid.

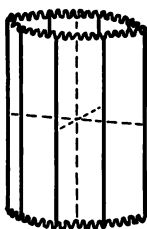


FIG. 62. — Ditetragonal prism.

**Synonyms for the Names of the Holohedral Tetragonal Forms.**

1st order pyramid — direct pyramid, 1st order bipyramid, or unit pyramid.

1st order prism — direct prism or unit prism.

2nd order pyramid — indirect pyramid or diametral pyramid.

2nd order prism — indirect prism or diametral prism.

Ditetragonal pyramid — ditetragonal bipyramid or zirconoid.

Ditetragonal prism — none.

Basal-pinacoid — basal-plane.

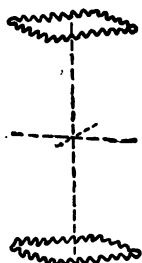


FIG. 63. — Basal pinacoid.

**Method of Determining Holohedral Tetragonal Forms by the Use of Symbols.**

After properly orienting the crystal in the manner already described select any face in the upper right

octant facing the observer, and ascertain the relative distances at which its plane intersects the three crystal axes, remembering that no face or face extended can cut the vertical axis at the same distance from the origin as it cuts either horizontal axis. If, for instance, it appears that the plane of the face selected intersects the three axes, but that the two horizontal axes are not cut at the same distance from the origin, the symbol of that face (and of the form of which it is a part) is  $a : na : mc$ . By referring to the table of holohedral tetragonal forms (which should be memorized as soon as possible) it is seen that the form is the ditetragonal pyramid. If more than one form is represented on the crystal, each may be determined in the same way.

**Suggestions for Attaining Facility in the Recognition of Forms.**

The holohedral tetragonal forms are so easily identified after they have been properly oriented that it seems almost unnecessary to offer rules aiming toward their rapid recognition.

The following statements may, however, prove useful to the beginner.

*1st order pyramid:* A single face lying wholly within an octant.

*1st order prism:* A vertical face cutting both horizontal axes equally.

*2nd order pyramid:* A face sloping down from the vertical axis directly towards the observer.

The 2nd order pyramid differs in no way from the 1st order pyramid excepting in position with respect to the horizontal crystal axes; and an 8-

8-faced pyramid may be placed in either the 1st or 2nd order position at will. Such a pyramid may, then, be considered either a 1st or 2nd order pyramid depending upon the set of interchangeable symmetry axes with which the crystal axes are chosen to coincide. It is only when forms in both the 1st and 2nd order positions are present on a crystal that it is necessary to distinguish between 1st and 2nd order pyramids.

*2nd order prism:* A vertical face extending from right to left or front to back.

As is the case with the 2nd order pyramid, a 2nd order prism differs in no way from a 1st order prism excepting in position with respect to the horizontal crystal axes; and all that was said in the preceding section relative to the 2nd order pyramid applies with equal truth to the 2nd order prism.

It is customary to select the horizontal crystal axes in such a way as will place the largest and most prominent 8-faced pyramid or 4-faced prism in the 1st order position.

Pyramids and prisms intersecting in horizontal edges are always of the same order.

*Ditetragonal pyramid:* Two identical faces lying wholly within an octant.

*Ditetragonal prism:* A vertical face cutting the two horizontal axes unequally.

*Basal-pinacoid:* A horizontal face on top of the crystal.

### **Fixed and Variable Forms.**

The only fixed holohedral tetragonal forms are the first and second order prism and the basal-pinacoid.

**Fixed Angles of the Tetragonal System.**

The only fixed angles in this system are those between the fixed forms just mentioned, namely,  $90^\circ$  and  $45^\circ$  (or  $135^\circ$ ).

**Miscellaneous.**

The general statements made in the discussion of the holohedral division of the isometric system regarding combination of forms, determination of the number of forms, repetition of forms on a crystal, and limiting forms applies with equal truth to all the divisions of the tetragonal system. It may be mentioned, however, that repetitions of the same variable form are very common in the tetragonal system, and crystal models showing such repeated forms are not difficult to obtain.

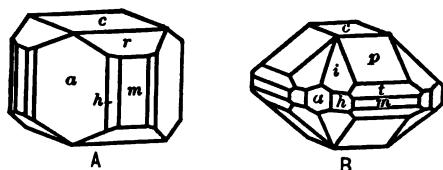


FIG. 64. — Holohedral tetragonal crystals.

A: Basal-pinacoid ( $c$ ), 1st order pyramid ( $r$ ), 1st order prism ( $m$ ), 2nd order prism ( $a$ ), and ditetragonal prism ( $h$ ).

B: Basal-pinacoid ( $c$ ), two 1st order pyramids ( $p$  and  $t$ ), 1st order prism ( $m$ ), 2nd order prism ( $a$ ), ditetragonal pyramid ( $i$ ), and ditetragonal prism ( $h$ ).



**SPHENOIDAL HEMIHEDRAL DIVISION****Development or Derivation of the Forms.**

Sphenoidal hemihedral forms may be conceived to be developed by dividing each of the holohedral forms by means of the principal symmetry plane and the *set of secondary symmetry planes containing the crystal axes* into eight parts, or octants, then suppressing all faces lying wholly within alternate parts thus obtained, and extending the remaining faces until they meet in edges or corners.

**Symmetry.**

Sphenoidal hemihedral forms possess only two interchangeable secondary symmetry planes at right angles to each other.

**Selection, Position, and Designation of the Crystal Axes.**

The three directions used as crystal axes in the holohedral division are still utilized for the same purpose in the sphenoidal hemihedral division. In other words, the vertical or *c* axis lies at the intersection of the two secondary symmetry planes; while the two interchangeable horizontal or *a* axes, one of which extends from front to back, and the other from right to left, make an angle of  $90^\circ$  with each other, and bisect the angles between the two secondary symmetry planes.

**Orienting Crystals.**

Sphenoidal hemihedral crystals are oriented in exactly the same way as are tetrahedral hemihedral isometric ones (see p. 30).

**Sphenoidal Hemihedral Tetragonal Forms Tabulated.**

Name.	Symbol.	Number of faces.	Form from which derived.
$\pm$ Tetragonal sphenoid (Fig. 65).....	$\pm \frac{a : a : mc}{2}$	4	1st order pyramid
$\pm$ Tetragonal scalenohedron (Fig. 66).....	$\pm \frac{a : na : mc}{2}$	8	ditetragonal pyramid
1st order prism (Fig. 58).....	$\frac{a : a : \infty c}{2}$	4	1st order prism
2nd order pyramid (Fig. 59)...	$\frac{a : \infty a : mc}{2}$	8	2nd order pyramid
2nd order prism (Fig. 60)....	$\frac{a : \infty a : \infty c}{2}$	4	2nd order prism
Ditetragonal prism (Fig. 62)...	$\frac{a : na : \infty c}{2}$	8	ditetragonal prism
Basal-pinacoid (Fig. 63).....	$\frac{\infty a : \infty a : c}{2}$	2	basal-pinacoid

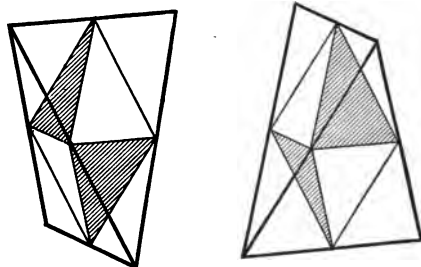


FIG. 65. — Positive (on left) and negative (on right) tetragonal sphenoids containing the forms from which they are derived. The suppressed faces are shaded.

**Synonyms for the Names of the Sphenoidal Hemihedral Tetragonal Forms.**

Tetragonal sphenoid — hemi-unit pyramid.

Tetragonal scalenohedron — none.

**Positive and Negative Forms in the Sphenoidal Hemihedral Tetragonal Division.**

+ and - forms are recognized in this division, and are distinguished in exactly the same way as are the + and - forms in the tetrahedral hemihedral

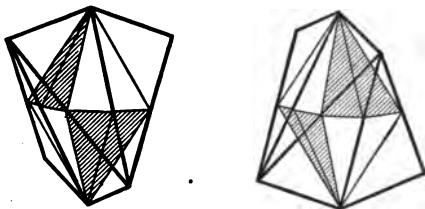


FIG. 66. — Positive (on left) and negative (on right) tetragonal scalenohedrons containing the forms from which they are derived. The suppressed faces are shaded.

division of the isometric system (see p. 32). All that was said there relative to such forms will apply with equal truth to the + and - forms in the division under consideration.

**Methods of Determining Sphenoidal Hemihedral Forms by the Use of Symbols.**

After properly orienting the crystal in the manner already described all the forms but the tetragonal sphenoid and scalenohedron may be identified easily by applying the rules already given for the determination of holohedral forms of the same name.

The tetragonal sphenoid and scalenohedron may be recognized by determining the symbol of any face in the manner described in the discussion of holohedral forms, dividing this symbol by 2, and then ascertaining from the table the name of the form possessing this symbol.

**Suggestions for Attaining Facility in the Recognition of Forms.**

Orient the crystal and determine which of the following descriptions (which should be learned at once) apply to the face or faces of different shape or size seen. Call the forms + or - according to the rules already set forth. It is assumed that the student is already familiar with the rules for recognizing those forms identical in shape with the holohedral ones (see p. 90).

*Tetragonal sphenoid:* A single face in an octant (although not necessarily wholly included therein) sloping down from the vertical axis in such a way as to cut both horizontal axes equally.

*Tetragonal scalenohedron:* Two faces lying within an octant (although not necessarily wholly included therein) which cut all three axes unequally.

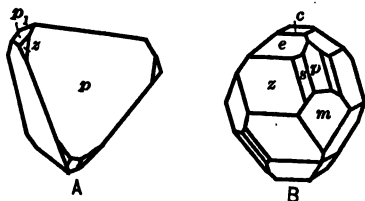


FIG. 67. — Sphenoidal hemihedral tetragonal crystals.

A: + and - tetragonal sphenoids ( $p$  and  $p_1$ ) and 2nd order pyramid ( $z$ ).

B: Basal pinacoid ( $c$ ), two 2nd order pyramids ( $e$  and  $z$ ), 1st order prism ( $m$ ), + tetragonal sphenoid ( $p$ ), and tetragonal scalenohedron ( $s$ ).

**PYRAMIDAL HEMIHEDRAL DIVISION****Development or Derivation of the Forms.**

Pyramidal hemihedral forms may be conceived to be developed by dividing each of the holohedral forms by means of all four secondary symmetry planes into eight parts, then suppressing all faces lying wholly within alternate parts thus obtained, and extending the remaining faces until they meet in edges or corners.

**Symmetry.**

Pyramidal hemihedral forms possess only one symmetry plane which is in the position of the principal symmetry plane existing in the holohedral division. It is, however, in the pyramidal hemihedral division a secondary rather than a principal symmetry plane since there are no interchangeable symmetry planes perpendicular to it.

Pyramidal hemihedral tetragonal forms may, then, be said to be characterized by the presence of one secondary symmetry plane and a general four-fold arrangement of the faces.

**Selection, Position, and Designation of the Crystal Axes.**

The vertical or *c* axis is made to coincide with the secondary symmetry axis. Two interchangeable horizontal axes parallel to prominent crystallographic directions at right angles to each other are also selected, one of which is so placed as to extend from front to back, and the other from right to left. Being interchangeable, both are called *a* axes.

**Orienting Crystals.**

The secondary symmetry plane is held horizontally. The crystal is then rotated around the symmetry axis until the most prominent pyramid or prism lies in the first order position. The crystal axes will then extend in the proper directions.

**Pyramidal Hemihedral Tetragonal Forms Tabulated.**

Name.	Symbol.	Number of faces.	Form from which derived.
3rd order pyramid (Fig. 68)...	$\frac{a : na : mc}{2}$	8	ditetragonal pyramid
3rd order prism (Fig. 69).....	$\frac{a : na : \infty c}{2}$	4	ditetragonal prism
1st order pyramid (Fig. 57)...	$\frac{a : a : mc}{2}$	8	1st order pyramid
1st order prism (Fig. 58).....	$\frac{a : a : \infty c}{2}$	4	1st order prism
2nd order pyramid (Fig. 59)...	$\frac{a : \infty a : mc}{2}$	8	2nd order pyramid
2nd order prism (Fig. 60).....	$\frac{a : \infty a : \infty c}{2}$	4	2nd order prism
Basal-pinacoid (Fig. 63).....	$\frac{\infty a : \infty a : c}{2}$	2	basal-pinacoid

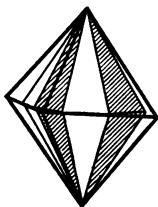


FIG. 68. — 3rd order pyramid containing the form from which it is derived. Suppressed faces are shaded.

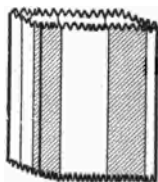


FIG. 69. — 3rd order prism containing the form from which it is derived. Suppressed faces are shaded.

**Synonyms for the Names of the Pyramidal Hemihedral Tetragonal Forms.**

3rd order pyramid — square pyramid of the third order or third order bipyramid.

3rd order prism — square prism of the third order.

**Method of Determining Pyramidal Hemihedral Tetragonal Forms by the Use of Symbols.**

After properly orienting the crystal in the manner already described all the forms but the 3rd order pyramid or prism may be identified easily by applying the rules already given for the determination of holohedral forms of the same name. The 3rd order pyramid or prism may be recognized by determining the symbol of any face in the manner already described in the discussion of holohedral isometric forms, dividing this symbol by 2, and then ascertaining from the table the name of the form possessing this symbol.

**Suggestions for Attaining Facility in the Recognition of Forms.**

Orient the crystal and determine which of the following descriptions (which should be learned at once) apply to the face or faces of different shape or size seen. It is possible, but unnecessary, to distinguish between positive and negative forms in this division. It is assumed that the student is already familiar with the rules for recognizing those forms identical in shape and position with the holohedral ones (see p. 90).

*3rd order pyramid:* A single face lying in an octant (although not necessarily wholly included therein)

which intersects all three crystal axes at different finite distances from the origin.

The 3rd order pyramid differs in no way from the 1st or 2nd order pyramid excepting in position with respect to the horizontal crystal axes. All three types of 8-faced pyramids may have the same appearance; and any such pyramid may be held at will as a 1st, 2nd, or 3rd order pyramid. The 3rd order pyramid is skewed or twisted through a small

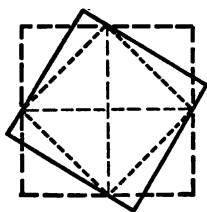
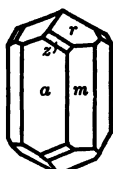
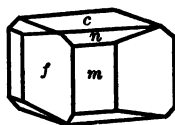


FIG. 70. — Diagram showing the relations of the 1st order (dotted lines), 2nd order (broken lines), and 3rd order (solid lines) pyramids and prisms to the horizontal crystal axes.



A



B

FIG. 71. — Pyramidal hemihedral hexagonal crystals.

A: 1st order pyramid ( $r$ ), 1st order prism ( $m$ ), 2nd order prism ( $a$ ), and 3rd order pyramid ( $z$ ).

B: Basal-pinacoid ( $c$ ), 1st order pyramid ( $n$ ), 1st order prism ( $m$ ), and 3rd order prism ( $f$ ).

angle (less than  $45^\circ$ ) either to the right or left away from the position of the 1st or 2nd order pyramid. Fig. 70 shows how the horizontal axes are cut by 1st, 2nd, and 3rd order pyramids and prisms.

*3rd order prism:* A single face parallel to the vertical axis, which intersects the two horizontal axes at unequal distances from the origin.

All that was said in the preceding section relative to the 3rd order pyramid applies with equal truth to the 3rd order prism.



**Application of the Law Governing Combination of Forms.**

It has already been noted (see p. 41) that one of the commonest mistakes made in determining crystal forms is the naming of two or more forms which cannot possibly occur on the same crystal, such, for instance, as the sphenoid and 3rd order pyramid. The presence on the same crystal of two forms like these, which are peculiar to different divisions of the system, is, of course, in direct violation of the law governing the combination of forms (see p. 36). A student should thoroughly familiarize himself with the following table if he wishes to avoid the mistake mentioned.

Holohedral forms.	Corresponding sphenoidal hemihedral forms.	Corresponding pyramidal hemihedral forms.
1st order pyramid.....	<i>tetragonal sphenoid</i>	1st order pyramid
1st order prism.....	1st order prism	1st order prism
2nd order pyramid.....	2nd order pyramid	2nd order pyramid
2nd order prism.....	2nd order prism	2nd order prism
Ditetragonal pyramid....	<i>tetragonal scalenohedron</i>	<i>3rd order pyramid</i>
Ditetragonal prism.....	ditetragonal prism	<i>3rd order prism</i>
Basal-pinacoid.....	basal-pinacoid	basal-pinacoid

It will be noted from the above table that the 1st order prism, 2nd order pyramid and prism, and the basal pinacoid occur in all three of the divisions already discussed, and may, therefore, be combined with any other forms in these divisions. Further, it will be seen that the 1st order pyramid and ditetragonal prism occur unchanged in name or shape in two of the divisions; while the ditetragonal pyramid occurs only as a holohedral form.

**TRAPEZOHEDRAL HEMIHEDRAL DIVISION**

Trapezohedral hemihedral forms may be conceived to be developed by dividing each holohedral form by the principal and all the secondary symmetry planes into sixteen parts, then suppressing all faces lying wholly within alternate parts thus obtained, and extending the remaining faces until they meet in edges or corners.

As the ditetragonal pyramid is the only tetragonal form with sixteen faces, it is evident that a ditetragonal pyramid face is the only one that can lie wholly within one of the parts obtained by dividing a tetragonal crystal in the manner just specified. The ditetragonal pyramid is, then, the only tetragonal form from which a trapezohedral hemihedral form differing from the holohedral one in shape and in name can be derived. This new form is called the tetragonal trapezohedron (Fig. 72). Since no mineral is known to crystallize in this division, its further consideration seems unnecessary.

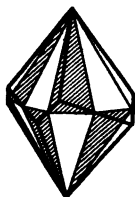


FIG. 72.—Tetragonal trapezohedron containing the form from which it is derived. The suppressed faces are shaded.

**Table of Holohedral Tetragonal Symbols Used by Various Authorities.**

	Weiss.	Naumann.	Dana.	Miller.
1st order pyramid.....	$a : a : mc$	$mP$	$m$	$hh$
1st order prism.....	$a : a : \infty c$	$\infty P$	$I$	110
2nd order pyramid.....	$a : \infty a : mc$	$mP \infty$	$m-i$	$hkl$
2nd order prism.....	$a : \infty a : \infty c$	$\infty P \infty$	$i-i$	100
Ditetragonal pyramid.....	$a : na : mc$	$mPn$	$m-n$	$hkl$
Ditetragonal prism.....	$a : na : \infty c$	$\infty Pn$	$i-n$	$hko$
Basal-pinacoid.....	$\infty a : \infty a : c$	$0P$	$O$	001

For methods of forming hemihedral symbols, see page 44.

## CHAPTER V

### ORTHORHOMBIC SYSTEM

#### HOLOHEDRAL DIVISION

##### **Symmetry.**

The holohedral division of the orthorhombic system is characterized by the presence of three non-interchangeable secondary symmetry planes at right angles to each other.

##### **The Selection, Position, and Designation of the Crystal Axes.**

The three crystal axes utilized in this system are so chosen as to coincide with the secondary symmetry

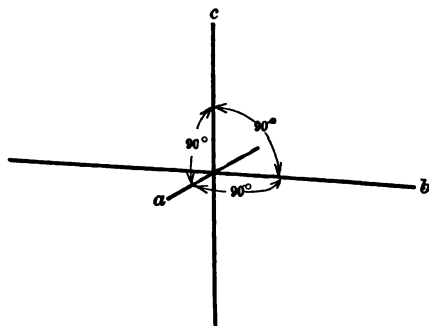


FIG. 73. — Crystal axes of the orthorhombic system.

axes. One is held vertically and is called the vertical or *c* axis; another is held horizontally from right to left, and is called the macro (long) or *b* axis; while

the third extends horizontally from front to back, and is called the brachy (short) or *a* axis. None of the three crystal axes are interchangeable (see Fig. 73).

### **Orienting Crystals.**

One symmetry plane is held so as to extend vertically from front to back, another vertically from right to left, and the third horizontally. The crystal axes will then extend in the proper directions, and the forms can be named according to the directions given later. There are, however, certain conventions that are set forth in immediately succeeding paragraphs, and which should be observed as closely as possible. In considering the statements that follow, it should be remembered that the relative lengths of the axes are determined by the distances from the origin to the points where the plane of a face of the ground-form intersects each crystal axis.

If a crystal is decidedly elongated, the longest axis becomes the *c* axis; while, if it is notably tabular, the shortest axis is used as the *c* axis. When neither elongated nor tabular an axis of intermediate length is used for the *c* axis.

The *c* axis having been selected, the longer of the other two axes is held from right to left as the macro or *b* axis, and the shorter from front to back as the brachy or *a* axis.

Since the student is unable to determine which form is the ground-form, and since the ground-form may not be represented on some crystals, it is permissible to determine the relative lengths of the

axes by noting the distances from the origin at which prominent faces intersect two or three axes.

### Holohedral Orthorhombic Forms Tabulated.

Name.	Symbol.	Number of faces.
Pyramid (Fig. 74).....	$na : b : mc$	8
Prism (Fig. 75).....	$na : b : \infty c$	4
Macro-dome (Fig. 76).....	$a : \infty b : mc$	4
Brachy-dome (Fig. 77).....	$\infty a : b : mc$	4
Macro-pinacoid (Fig. 78).....	$a : \infty b : \infty c$	2
Brachy-pinacoid (Fig. 79).....	$\infty a : b : \infty c$	2
Basal-pinacoid (Fig. 80).....	$\infty a : \infty b : c$	2

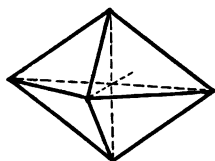


FIG. 74. — Pyramid.

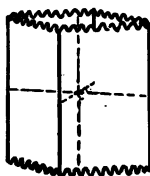


FIG. 75. — Prism.

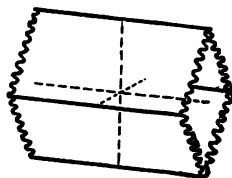


FIG. 76. — Macro-dome.

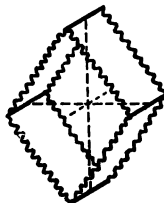


FIG. 77. — Brachy-dome.

**Remarks on the Holohedral Orthorhombic Forms.**

It will be seen by examining the table just given that the holohedral orthorhombic forms may be grouped into three divisions, one containing the pyramid with eight faces cutting all three axes at

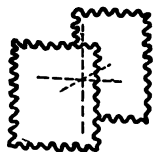


FIG. 78. — Macro-pinacoid.

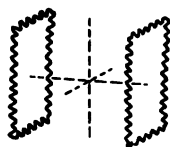


FIG. 79. — Brachy-pinacoid.

finite distances, one containing the prism and domes with four faces parallel to one axis and cutting the other two at finite distances, and one containing the pinacoids with two faces parallel to

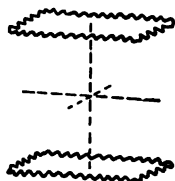


FIG. 80. — Basal-pinacoid.

two axes. The forms in any one of these divisions may be changed into any other form in the same division by a different selection of crystal axes; but a form in no one division can be named as a form in any of the other divisions no matter how the crystal is held. The pyramid is the only holohedral orthorhombic form which will when unmodified completely bound the crystal. Since all the forms but the pinacoids (the fixed forms) contain one or more variables in their symbols, they may be repeated an indefinite number of times on the same crystal.

Domes and pinacoids (excepting the basal-pinacoid) are named by prefixing the name of the horizontal axis to which they are parallel.

**Synonyms for the Names of the Holohedral Orthorhombic Forms.**

Pyramid — unit-pyramid, macro-pyramid, and brachy-pyramid.

Prism — unit-prism, macro-prism, and brachy-prism.

Macro-dome — none.

Brachy-dome — none.

Macro-pinacoid — none.

Brachy-pinacoid — none.

Basal-pinacoid — basal-plane.

**Method of Determining Holohedral Orthorhombic Forms by the Use of Symbols.**

The usual method of determining forms by the use of symbols, as presented in the discussion of the systems already described, may be used successfully in the orthorhombic system. In forming symbols it should be remembered that the distance from the origin to the point where the plane of any face intersects the macro or  $b$  axis is always made  $b$  (or  $\infty b$  if the face is parallel to this axis); while the distance from the origin to the point where the plane of the face intersects the brachy or  $a$  axis is called  $na$  (or  $\infty a$ ) if the plane cuts the  $b$  axis at a finite distance from the origin, and is called  $a$  (or  $\infty a$ ) if the plane cuts the  $b$  axis at infinity. Similarly, the distance from the origin to the point where the plane of a face intersects the  $c$  axis is called  $mc$  (or  $\infty c$ ) if the plane cuts either the  $a$  or  $b$  axes at

finite distances; while it is called  $c$  if both the  $a$  and  $b$  axes are cut at infinity.

**Suggestions for Attaining Facility in the Recognition of Forms.**

Orient the crystal and determine which of the following descriptions (which should be learned at once) apply to the face or faces of different shape or size seen.

*Pyramid*: A face lying entirely within an octant.

*Prism*: A vertical face oblique to both horizontal axes.

*Macro-dome*: A face sloping from the vertical axis directly down toward the observer.

*Brachy-dome*: A face sloping from the vertical axis down to the right or left.

*Macro-pinacoid*: A vertical face extending from right to left.

*Brachy-pinacoid*: A vertical face extending from front to back.

*Basal-pinacoid*: A horizontal face on top of the crystal.

**Fixed and Variable Forms.**

The only fixed holohedral orthorhombic forms are the three pinacoids.

**Fixed Angles of the Orthorhombic System.**

The only fixed angle in this system is that between the three pinacoids, namely,  $90^\circ$ .

**Miscellaneous.**

The general statements made in the discussion of the holohedral division of the isometric system



regarding combination of forms, determination of the number of forms, and limiting forms apply with equal truth to all the divisions of the tetragonal system. Hemimorphism (see p. 17) is shown by crystals of calamine as well as by those of certain rare minerals.

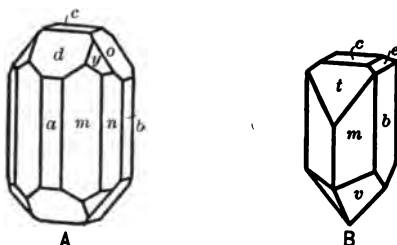


FIG. 81. — Holohedral orthorhombic crystals.

A: Basal-pinacoid (*c*), macro-dome (*d*), macro-pinacoid (*a*), brachy-dome (*o*), brachy-pinacoid (*b*), pyramid (*y*), and two prisms (*m* and *n*).

B (hemimorphic): Basal-pinacoid (*c*), brachy-dome (*e*), brachy-pinacoid (*b*), macro-dome (*t*), and prism (*m*). On other end: pyramid (*v*).

## SPHENOIDAL HEMIHEDRAL DIVISION

### Development or Derivation of the Forms.

Sphenoidal hemihedral forms may be conceived to be developed by dividing each of the holohedral forms by means of the three secondary symmetry planes into eight parts, then suppressing all faces lying wholly within alternate parts thus obtained, and extending the remaining faces until they meet in edges or corners.

### Symmetry.

Sphenoidal hemihedral forms possess no symmetry planes whatever, but are characterized by the presence of three

prominent, non-interchangeable crystallographic directions at right angles to each other.

### Selection, Position, and Designation of the Crystal Axes.

Three prominent, non-interchangeable crystallographic directions at right angles to each other are selected as the crystal axes. These are held and named exactly as in the holohedral division.

### Orienting Crystals.

Usually the easiest way to orient sphenoidal hemihedral crystals is to identify by general appearance some form whose holohedral and hemihedral shapes are the same, and to hold this form in the position it occupies in the holohedral division. It is often just as easy or easier to find three prominent, non-interchangeable crystallographic directions at right angles to each other, and to hold these in the positions of the crystal axes, in the manner already set forth in the discussion of the holohedral division.

### Sphenoidal Hemihedral Orthorhombic Forms Tabulated.

Name.	Symbol.	Number of faces.	Form from which derived.
$\pm$ Orthorhombic sphenoid (Fig. 82).....	$\pm \frac{na : b : mc}{2}$	4	pyramid
Prism (Fig. 75).....	$\frac{na : b : \infty c}{2}$	4	prism
Macro-dome (Fig. 76).....	$\frac{a : \infty b : mc}{2}$	4	macro-dome
Brachy-dome (Fig. 77).....	$\frac{\infty a : b : mc}{2}$	4	brachy-dome
Macro-pinacoid (Fig. 78).....	$\frac{a : \infty b : \infty c}{2}$	2	macro-pinacoid
Brachy-pinacoid (Fig. 79).....	$\frac{\infty a : b : \infty c}{2}$	2	brachy-pinacoid
Basal-pinacoid (Fig. 80).....	$\frac{\infty a : \infty b : c}{2}$	2	basal-pinacoid

**Synonyms for the Names of Sphenoidal Hemihedral Tetragonal Forms.**

Orthorhombic sphenoid — none.

**Positive and Negative Forms in the Sphenoidal Hemihedral Division.**

+ and - forms are recognized in this division, and are distinguished in exactly the same way as are the + and - forms in the tetrahedral hemihedral division of the isometric system (see p. 32). All that was said there relative to such forms will apply with equal truth to the + and - forms in the division under consideration.

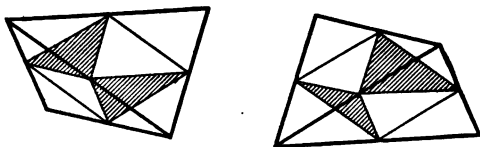


FIG. 82. — Positive (on left) and negative (on right) orthorhombic sphenoids containing the forms from which they are derived. The suppressed faces are shaded.

**Method of Determining Sphenoidal Hemihedral Forms by the Use of Symbols.**

After properly orienting the crystal in the manner already described all the forms but the orthorhombic sphenoid may be identified easily by applying the rules already given for the determination of holohedral forms of the same name.

The orthorhombic sphenoid may be recognized by determining the symbol of any face in the manner described in the discussion of holohedral forms, dividing this symbol by two, and then ascertaining from the table the name of the form possessing this symbol.

**Suggestions for Attaining Facility in the Recognition of Forms.**

After properly orienting the crystal all the forms but the orthorhombic sphenoid may be recognized by the rules al-

ready given for identifying the holohedral forms (see p. 108). The following description of the position of an orthorhombic sphenoid face should be learned at once; and if faces answering to this description are present on a crystal, they should be called + or - according to the rules already set forth.

*Orthorhombic Sphenoid:* A single face in an octant (although not necessarily wholly included therein) sloping down from the vertical axis so as to cut both horizontal axes obliquely.

**Table of Holohedral Orthorhombic Symbols Used by Various Authorities.**

	Weiss.	Naumann.	Dana.	Miller.
Pyramid.....	$na : b : mc$	$m$ or $mPn$	$1$ or $m-n$	$111$ or $hkl$
Prism.....	$na : b : \infty c$	$mP$ or $\infty Pn$	$1$ or $1-n$	$110$ or $hk0$
Macro-dome.....	$a : \infty b : mc$	$mP \infty$	$m-i$	$h0l$
Brachy-dome.....	$\infty a : b : mc$	$mP \infty$	$m-i$	$0kl$
Macro-pinacoid.....	$a : \infty b : \infty c$	$\infty P \infty$	$i-i$	$100$
Brachy-pinacoid.....	$\infty a : b : \infty c$	$\infty P \infty$	$i-i$	$010$
Basal-pinacoid.....	$\infty a : \infty b : c$	$0P$	$0$	$001$

For methods of forming hemihedral symbols, see p. 44.

## CHAPTER VI

### MONOCLINIC SYSTEM

#### HOLOHEDRAL DIVISION

#### Symmetry.

The holohedral division of the monoclinic system is characterized by the presence of one secondary symmetry plane.

#### Selection, Position, and Designation of the Crystal Axes.

The ortho or *b* crystal axis is made to coincide with the secondary symmetry axis, and is held horizontally from right to left. The other two axes (which are made to pass through the geometric center of the crystal) are selected lying in the symmetry plane parallel to two prominent crystallographic directions as nearly at right angles to each other as possible. One is held vertically and called the vertical or *c* axis; while the other is held so as to slope or incline *down* toward the observer, and is called the clino or *a* axis (see Fig. 83).

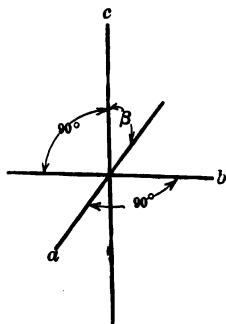


FIG. 83. — Crystal axes of the monoclinic system.  $\beta$  is a variable angle, but can never be equal to a fixed angle of any system.

None of the crystal axes are interchangeable.

The ortho axis makes right angles with both the

vertical and the clino axes, but the clino and vertical axes are never exactly at right angles to each other.

### **Orienting Crystals.**

The symmetry plane is held so as to extend vertically from front to back. The crystal is then rotated around the symmetry (ortho) axis until the most prominent crystallographic direction (which fixes the position of the *c* axis) is held vertically, and a second prominent crystallographic direction (which fixes the position of the clino axis) is held so as to slope or incline down toward the observer.

*Prominent crystallographic directions* may be edges, the intersection of the symmetry plane and faces, or lines connecting opposite corners or the middle points of opposite edges or faces. It will usually be found desirable to select the vertical and clino axes parallel to prominent *edges*, unless by so doing the two axes mentioned are forced to intersect in a decidedly acute angle.

### **Holohedral Monoclinic Forms Tabulated.**

Name.	Symbol.	Number of faces.
+Pyramid (Fig. 84).....	$-na : b : mc$	4
-Pyramid (Fig. 85).....	$+na : b : mc$	4
Prism (Fig. 86).....	$na : b : \infty c$	4
Clino-dome (Fig. 87).....	$\infty a : b : mc$	4
Ortho-pinacoid (Fig. 88).....	$a : \infty b : \infty c$	2
+Ortho-dome (Fig. 89).....	$-na : \infty b : mc$	2
-Ortho-dome (Fig. 90).....	$+na : \infty b : mc$	2
Basal-pinacoid (Fig. 91).....	$\infty a : \infty b : c$	2
Clino-pinacoid (Fig. 92).....	$\infty a : b : \infty c$	2

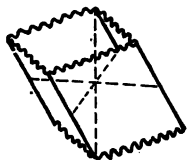


FIG. 84. — Positive pyramid.

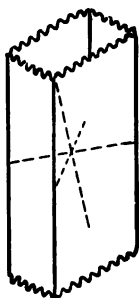


FIG. 85. — Negative pyramid.

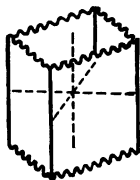


FIG. 86.  
Prism.

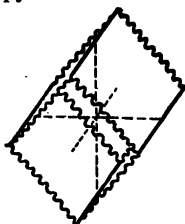


FIG. 87.  
Clino-dome.

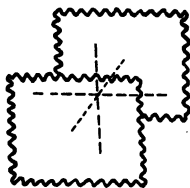


FIG. 88.  
Ortho-pinacoid.

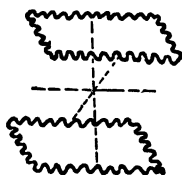


FIG. 89. — Positive  
ortho-dome.

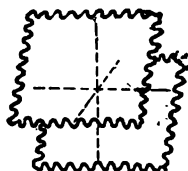


FIG. 90. — Negative  
ortho-dome.

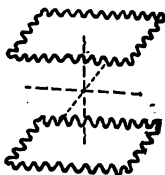


FIG. 91. — Basal-pinacoid.

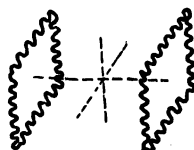


FIG. 92. — Clino-pinacoid.

**Remarks on the Holohedral Monoclinic Forms.**

It will be seen by examining the table just given that the holohedral monoclinic forms may be grouped into three divisions, one containing forms whose faces intersect the symmetry plane obliquely, namely, the  $+$  and  $-$  pyramid, clino-dome, and prism; another containing forms whose faces are perpendicular to the symmetry plane, namely, the ortho-pinacoid,  $+$  and  $-$  ortho-dome, and basal-pinacoid; and a third containing a form whose faces are parallel to the symmetry plane, namely, the clino-pinacoid. The forms in any one of these divisions may be changed into any other form in the same division by a different selection of crystal axes; but a form in no one division can be named as a form in any of the other divisions no matter how the crystal is held.

Since all the forms but the pinacoids (the fixed forms) contain one or more variables in their symbols, they may be repeated an indefinite number of times on the same crystal. No one form in this system will completely bound a crystal. In other words, at least two forms must always be represented on a monoclinic crystal.

Domes and pinacoids (excepting the basal-pinacoid) are named by prefixing the name of the horizontal axis to which they are parallel.



**Synonyms for the Names of the Holohedral Monoclinic Forms.**

Pyramid — unit-, ortho-, and clino-hemipyramid.

Prism — unit-, ortho-, and clino-prism.

Clino-dome — none.

Ortho-pinacoid — none.

Ortho-dome — none.

Basal-pinacoid — basal-plane.

Clino-pinacoid — none.

**Positive and Negative Forms in the Holohedral Monoclinic Division.**

The + and - forms in this system are distinguished in quite a different manner from the + and - forms in any of the systems already discussed, and are apt to prove quite confusing to a student until he is thoroughly familiar with the conceptions upon which their distinction is based.

It has been decided to call those pyramids and ortho-domes — whose faces or faces extended intersect the clino axis in *front* of the origin (at  $+na$ ); while those pyramids and ortho-domes whose faces or faces extended intersect the clino axis *behind* the origin (at  $-na$ ) are called +. In other words, the + forms lie over the acute angle ( $\beta$ , Fig. 83) formed by the intersection of the vertical and the clino axes, while the - forms lie over the obtuse angle between these axes.

It should be noted that the + forms have a - sign, while the - forms have a + sign in their symbols. This inconsistency is unfortunate, but the practice of naming these forms in the manner specified has become so firmly established that it

appears impossible to change the nomenclature. The following rule will be found useful in distinguishing between + and - pyramids:

A + pyramid intersects the basal-pinacoid on top of a crystal in edges which converge *away* from the observer.

A - pyramid intersects a basal-pinacoid on top of a crystal in edges which converge *toward* the observer.

**Reason Why Faces on Top or in Front of a Crystal are Duplicated at the Bottom or Back.**

It is easy to understand why the clino-pinacoid faces are duplicated on both sides of a crystal, since the presence of a symmetry plane requires such duplication. It is not so easy to understand, however, why the faces of the other forms are duplicated on the top and bottom and front and back, since no symmetry plane lies between such duplicated faces. The reason for this duplication is found in the law of axes which states that opposite ends of crystal axes must be cut by the same number of similar faces similarly placed. In order that this law shall hold good no matter how the vertical and clino axes are chosen, it is necessary that faces be duplicated in the manner mentioned.

**Method of Determining Holohedral Monoclinic Forms by the Use of Symbols.**

The method outlined in the presentation of the orthorhombic system (see p. 107) may be applied with equal facility to the monoclinic system, although the conception of + and - forms already

outlined must be borne in mind when naming pyramids and ortho-domes.

**Suggestions for Attaining Facility in the Recognition of Forms.**

Orient the crystal and determine which of the following descriptions apply to the face or faces of different shape or size seen.

+ *Pyramid*: A face whose plane cuts all three axes at finite distances from the origin, and the clino axis behind the vertical axis.

– *Pyramid*: A face whose plane cuts all three axes at finite distances from the origin, and the clino axis in front of the vertical axis.

*Climo-dome*: A face sloping from the vertical axis down to the right or left and parallel to the clino axis.

A clino-dome may often be distinguished with ease from the + or – pyramid if it is remembered that its faces intersect a basal-pinacoid or another clino-dome in edges that are parallel.

*Prism*: A vertical face oblique to the ortho axis.

*Ortho-pinacoid*: A vertical face extending from right to left.

+ *Ortho-dome*: A face whose plane is parallel to the ortho axis, and cuts the clino axis behind the origin.

– *Ortho-dome*: A face sloping down from the vertical axis directly toward the observer, and cutting the clino axis in front of the origin.

*Basal-pinacoid*: A face sloping down from the vertical axis directly toward the observer and parallel to the clino axis.

**Clino-pinacoid:** A vertical face extending from front to back.

**Fixed and Variable Forms.**

The only holohedral monoclinic fixed forms are the three pinacoids.

**Fixed Angles of the Monoclinic System.**

The only fixed angle in this system is that between the clino- and the ortho- or basal-pinacoid, namely,  $90^\circ$ .

**Miscellaneous.**

The general statements made in the discussion of the holohedral division of the isometric system regarding combination of forms, determination of the number of forms, and limiting forms apply with equal truth to this system.

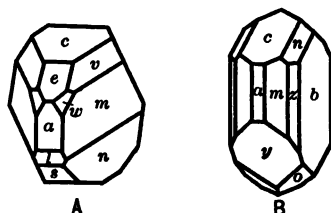


FIG. 93. — Holohedral monoclinic crystals.

A: (clino axis selected parallel to the face lettered *c*): basal-pinacoid (*c*), — ortho-dome (*e*), two + ortho-domes (*l* and *s*), two — pyramids (*v* and *w*), + pyramid (*n*), prism (*m*), and ortho-pinacoid (*a*).

B: (clino axis selected parallel to the face lettered *c*): basal-pinacoid (*c*), + ortho-dome (*y*), ortho-pinacoid (*a*), clino-dome (*n*), clino-pinacoid (*b*), + pyramid (*o*), and two prisms (*m* and *z*).

**Hemihedral and Hemimorphic Forms.**

Hemihedral and hemimorphic forms are too rare to require consideration.

**Table of Holohedral Monoclinic Symbols Used by Various Authorities.**

	Weiss.	Naumann.	Dana	Miller.
+Pyramid .....	$-na : b : mc$	$+mP$ or $+mPn$	$+m$ or $+m-n$	$\bar{h}hl$ or $\bar{h}kl$
-Pyramid .....	$+na : b : mc$	$-mP$ or $-mPn$	$-m$ or $-m-n$	$hhl$ or $hkl$
Prism .....	$na : b : \infty c$	$\infty P$ or $\infty Pn$	$I$ or $i-n$	$110$ or $hk0$
Clino-dome .....	$\infty a : b : mc$	$mP \infty$	$m-i$	$0kl$
Ortho-pinacoid ...	$a : \infty b : \infty c$	$\infty P \infty$	$i-i$	$100$
+Ortho-dome ....	$-na : \infty b : mc$	$+mP \infty$	$+m-i$	$\bar{h}0l$
-Ortho-dome ....	$+na : \infty b : mc$	$-mP \infty$	$-m-i$	$h0l$
Basal-pinacoid ...	$\infty a : \infty b : c$	$0P \infty$	$0$	$001$
Clino-pinacoid ..	$\infty a : b : \infty c$	$\infty P \infty$	$i-i$	$000$

## CHAPTER VII

### TRICLINIC SYSTEM

#### HOLOHEDRAL DIVISION

##### **Symmetry.**

The triclinic system is characterized by the absence of any kind of symmetry plane.

##### **Selection, Position, and Designation of the Crystal Axes.**

Three crystal axes are selected parallel to prominent crystallographic directions (see p. 114) and at as nearly right angles to each other as possible. These are held and named exactly as in the orthorhombic system (see p. 103) excepting that the macro axis extending from right to left and the brachy axis extending from front to back will not be horizontal; and none of the axes are at right angles to each other, nor can the angles between them be the fixed angles of any system.

##### **Orienting Crystals.**

The three crystal axes having been selected, the one chosen as the *c* axis is held vertically; the shorter of the other two axes (the brachy axis) is so held as to slope down directly toward the observer. The macro axis will, then, extend from right to left, intersecting the plane through the vertical and brachy axes more or less obliquely.

The *c* axis is selected according to the conventions already given in the discussion of the orthorhombic system (see p. 104).

### **Triclinic Forms Discussed.**

The triclinic forms have exactly the same names and symbols as the corresponding orthorhombic forms (see p. 105), but differ therefrom in that each triclinic form consists of only a single pair of parallel and opposite faces.

Since each form in this system consists of but two faces, it follows that the forms differ from one another only as regards their position with respect to the crystal axes; and any form may be changed into any other form by selecting the crystal axes so as to run in the proper direction. If, however, the conventions with respect to the choice of the axes are observed, different observers will in most cases designate all the forms by the same names.

### **Synonyms for the Names of the Triclinic Forms.**

Pyramid — unit-, brachy-, and macro-tetrapyramid.

Prism — unit-, brachy-, and macro-hemiprism.

Macro-dome — hemi-macro-dome.

Brachy-dome — hemi-brachy-dome.

Macro-pinacoid — none.

Brachy-pinacoid — none.

Basal-pinacoid — basal-plane.

### **Reason Why All Triclinic Forms Consist of *Two* Parallel Faces.**

It is not at first easy to see why a face on one side of a triclinic crystal must be duplicated on the

opposite side, since no symmetry plane lies between these faces; but the law of axes states that opposite ends of crystal axes must be cut by the same number of similar faces similarly placed; and, in order that this law shall hold good no matter how the crystal axes are chosen, it is necessary that faces be duplicated in the manner mentioned.

**Method of Determining Triclinic Forms by the Use of Symbols.**

The method already outlined in the discussion of the other crystal systems may be applied with equal facility to the triclinic system, in which it is not necessary to distinguish between + and - forms. Care must be taken to give a name to every pair of opposite and parallel faces.

**Suggestions for Attaining Facility in the Recognition of Forms.**

When the axes are nearly perpendicular to each other, it is possible to determine the forms by slightly modifying the rules already given for determining those of the same name in the orthorhombic system (see p. 108). The modifications required are those introduced by the fact that none of the axes lie at right angles to each other. In many cases, however, the forms can be determined most readily by noting the relationship of the faces with respect to the axes, which is really equivalent to determining the symbol of each face. The following descriptions of the forms are based on their relationship to the axes, and may be applied after a crystal is properly oriented.



*Pyramid:* A face whose plane cuts all three crystal axes at finite distances from the origin.

In order to determine the number of pyramids, it is necessary to count all the pyramidal faces lying above a plane passed through the macro and brachy axes.

*Prism:* A vertical face whose plane intersects both the macro and brachy axes at finite distances from the origin.

In order to determine the number of prisms, it is necessary to count all the prismatic faces lying in front of a plane passed through the macro and vertical axes.

*Macro-dome:* A face whose plane is parallel to the macro axis and intersects the vertical and the brachy axes at finite distances from the origin.

In order to determine the number of macro-domes, it is necessary to count all such faces lying above a plane passed through the macro and brachy axes.

*Brachy-dome:* A face whose plane is parallel to the brachy axis and intersects the macro and vertical axes at finite distances from the origin.

In order to determine the number of brachy-domes, it is necessary to count the number of such faces lying above a plane passed through the macro and brachy axes.

*Macro-pinacoid:* A vertical face parallel to the macro and vertical axes.

There can be but one macro-pinacoid on a crystal.

*Brachy-pinacoid:* A vertical face extending from front to back (parallel to the brachy and vertical axes).

There can be but one brachy-pinacoid on a crystal.

*Basal-pinacoid:* A face (not horizontal) parallel to the macro and brachy axes.

There can be but one basal-pinacoid on a crystal.

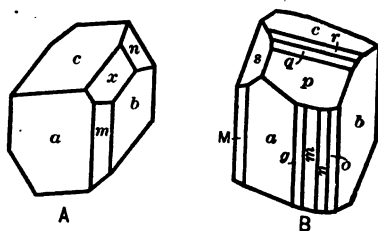


FIG. 94. — Holohedral triclinic crystals.

A: (vertical axis selected parallel to the edge between  $a$  and  $m$ , macro axis parallel to the edge between  $c$  and  $a$ , and brachy axis parallel to the edge between  $b$  and  $x$ ): basal-pinacoid ( $c$ ), macro-pinacoid ( $a$ ), brachy-pinacoid ( $b$ ), brachy-dome ( $x$ ), pyramid ( $n$ ), and prism ( $m$ ).

B: (vertical axis selected parallel to the edge between  $a$  and  $M$ , macro-axis parallel to the edge between  $c$  and  $a$  at the upper right edge of the figure, and brachy axis parallel to the edge between  $c$  and  $b$ ): basal-pinacoid ( $c$ ), macro-pinacoid ( $a$ ), brachy-pinacoid ( $b$ ), four pyramids ( $p$ ,  $q$ ,  $r$  and  $s$ ), and five prisms ( $M$ ,  $g$ ,  $m$ ,  $n$  and  $o$ ).

In order to attain facility in the recognition of triclinic forms, it will be found advisable to practice determining them when the crystal axes are so selected as to make decidedly acute angles with each other. When the student is able to name the forms correctly under such conditions he will find it very easy to do so when the axes are properly selected at as nearly right angles as possible.

**Miscellaneous.**

The general statements made in the discussion of the holohedral division of the isometric system regarding combination of forms, determination of the number of forms, and limiting forms apply with equal truth to this system.

**Hemihedral, Tetartohedral, and Hemimorphic Triclinic Forms.**

Since the triclinic system contains no symmetry planes, it is impossible to develop hemihedral or tetartohedral forms according to the general rules already given (see p. 17). Hemimorphic forms are practically unknown.

## CHAPTER VIII

### TWINS

#### **A Twin Defined.**

A twin may be defined as two or more crystals or portions of one crystal so united that, if alternate crystals or portions could be revolved  $180^\circ$  on a so-called twinning plane or planes, one simple untwinned crystal would be formed. See Figs. 95 to 99.

It is, of course, not supposed that Nature actually revolves alternate crystals or portions of a crystal after the simple or untwinned crystals have started to form. The definition just given is, then, merely a statement of tests which may be applied to ascertain whether a given crystal or group of crystals is a twin. Since the cause of the development of twins is unknown, and since there are several classes differing in appearance, it is impossible to formulate a definition based either on genesis or appearance, but some authorities define a twin as two or more crystals or portions of a crystal united according to some definite law.

Most twins are characterized by the presence of re-entrant angles, but the same peculiarity is shown by groups of crystals not united according to the laws of twinning, so this feature cannot be considered distinctive of twins.

**Preliminary Definitions.**

*A Twinning Plane Defined:* A twinning plane is a plane so located with reference to two twinned crystals or portions of a crystal that, if one of these crystals or portions of a crystal could be revolved  $180^\circ$  on the plane, the two crystals or portions of a crystal would then be in untwinned relationship to each other (see Fig. 95). A twinning plane is named by stating the name of the possible crystal faces to which it is parallel.

A twinning plane can never be parallel to a symmetry plane excepting in the tetrahedral hemihedral division of the isometric system and the sphenoidal hemihedral division of the tetragonal system, and must be parallel to possible crystal faces.

*Twinning Axis Defined:* A twinning axis is a line or direction perpendicular to a twinning plane. The twinning axis usually passes through the geometric center of the crystal.

*Plane of Union or Composition Face Defined:* The plane of union or composition face is a plane along which two crystals or portions of a crystal appear to be united to form a twin. It may or may not coincide in position with the twinning plane. The plane of union must be parallel to a possible crystal form, and is named by stating the name of the possible crystal faces to which it is parallel.

**Classes of Twins.**

Three classes of twins are generally recognized, namely, contact, interpenetration, and multiple twins. The last named class may be subdivided into subclasses called oscillatory and cyclic twins.

Each of these classes will be discussed in the order mentioned.

*Contact Twin Defined:* A contact twin is one in which *two portions of a crystal* appear to have been united along a common plane after one portion has been revolved  $180^\circ$  relative to the other (see Fig. 95). The twinning plane and plane of union usually coincide in contact twins.

Contact twins are simpler and commoner than any of the other types, and present no special difficulties.

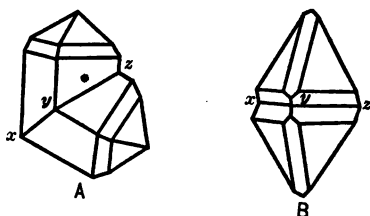


FIG. 95. — Contact twins. A is tetragonal, and B is monoclinic. Positions of the twinning planes indicated by *xyz*.

In studying and reciting upon any type of twin a student should determine and state the following facts:

I. The class of the twin (contact, interpenetration, etc.).

II. The system and division to which the crystal belongs.

III. The forms present on the crystal.

IV. The name of the form whose face or faces the twinning plane parallels.

V. The name of the form whose face or faces the plane of union parallels.

In determining the system of a contact twin and the forms present thereon, it is usually advisable to cover with the hand that portion of the crystal at one side of the twinning plane and to examine only the portion left uncovered. If this is not done, a beginner is apt to be confused by the more or less unsymmetrical arrangement of faces on the two portions of the crystal separated by the twinning plane.

*Interpenetration Twin Defined:* An interpenetration twin is one in which two or more *complete* crystals

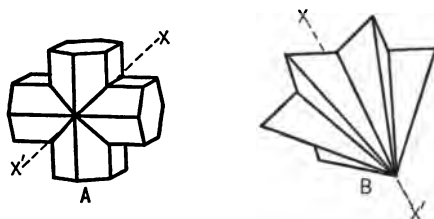


FIG. 96. — Interpenetration twins. A is orthorhombic and B is tetrahedral hemihedral isometric. Positions of the twinning axes indicated by  $X-X'$ .

*tals* appear mutually to penetrate into and through each other according to the laws of twinning (see Fig. 96).

It is usually comparatively easy to determine the plane of union and the system and division of such twins, together with the forms present thereon; but it is more difficult to determine the name of the form whose face or faces the twinning plane parallels. It will be found advisable to seek the twinning axis, and, when this is found, determine the name of the form with a face or faces perpendicular to this axis.

Such a form will, of course, have faces parallel to the twinning plane. To determine the position of the twinning axis, hold a pencil with one end against various points on the crystal, and ascertain whether it is possible to bring all points on one of the interpenetrating crystals into the position of identical points on another of the interpenetrating crystals by imagining a rotation of all points on the first crystal  $180^\circ$  around the axis represented by the pencil. If such a rotation would cause the two crystals to coincide, it may be assumed that the pencil is in the position of the twinning axis sought, provided that a plane perpendicular to the pencil is parallel to a possible crystal face.

*Multiple Twin Defined:* A multiple twin is one in which *more than two portions* of a single crystal appear alternately to have been revolved  $180^\circ$  upon parallel or non-parallel twinning planes. Two adjacent parts separated by a twinning plane possess relationships very similar to those of the two parts of a contact twin.

*Oscillatory Twin Defined:* An oscillatory twin is a multiple twin in which the alternate portions appear to have been revolved  $180^\circ$  upon *parallel* twinning planes (see Fig. 97).

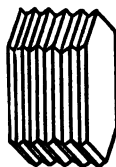


FIG. 97. — Oscillatory multiple twin.

In studying multiple twins, only a portion bounded on one side by a twinning plane and elsewhere by crystal faces should be examined, as other portions included between two parallel twinning planes are apt to possess such a deficiency of faces as to make



the determination of the system, division, and forms difficult or impossible.

*Cyclic Twin Defined:* A cyclic twin is a multiple twin in which alternate portions appear to have been revolved  $180^\circ$  upon *non-parallel* twinning planes (see Fig. 98).

The rotation of alternate parts  $180^\circ$  on non-parallel twinning planes tends to give these twins a ring-like form. In cases where a small number of parts are involved, or where the twinning planes are nearly parallel, the ring will be incomplete; but, when the number of parts are higher or the twinning planes depart considerably from parallelism, a complete ring may result. The center of such a ring of twinned portions may be hollow, or the twinned portions may be in contact in the center. If the cyclic twin forms an incomplete ring, it is comparatively easy to determine all the forms according to the method suggested in the discussion of oscillatory twins; but, if a complete ring is formed, some of the crystal faces necessary in order to cover completely an individual crystal may be missing.

When cyclic twins have the form of complete rings it is customary to give them a name depending upon the number of twinned portions, as trilling, fourling, sixling, eightling, etc.

Interpenetration twins are often of cyclic type as illustrated by Fig. 99.

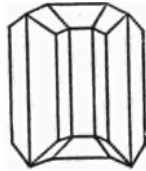


FIG. 98. — Cyclic multiple twin.

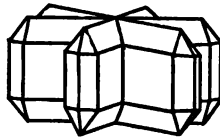


FIG. 99. — Multiple interpenetration twin.

**Influence of Twinning Upon Symmetry.**

The twinning plane often appears to be a symmetry plane. Whether this will be the case or not depends upon the character of the crystal and the position of the plane as set forth in the following statement:

The twinning plane will always appear to be a symmetry plane if the crystal is entirely bounded by forms whose faces are arranged in parallel pairs, and if the twinning plane passes through the center of the crystal.

While twinning often apparently introduces a symmetry plane in a crystal, it may also result in the elimination of some symmetry planes. Whether it will have the latter effect or not depends upon the degree of symmetry of the untwinned crystal, and the position of the twinning plane. It may, however, be said that in general twinned crystals belonging to systems or divisions of systems characterized by the presence of more than two symmetry planes often appear to have their symmetry decreased; while crystals belonging to systems characterized by the presence of less than two symmetry planes usually appear to have their symmetry increased. For instance, the twinned holohedral tetragonal crystal shown in Fig. 95A appears to have only two symmetry planes instead of five symmetry planes which the untwinned crystal possesses; while the twinned monoclinic crystal shown in Fig. 95B appears to have two symmetry planes instead of the single one characteristic of the untwinned crystal.

**Possible and Impossible Twinning Planes.**

It has already been mentioned that a twinning plane must be parallel to a possible crystal face, and cannot be parallel to a symmetry plane. The student will find it a good review of his knowledge of the positions of the symmetry planes and forms in each division of every system if he will attempt to write out a complete list of all the forms parallel to which twinning planes *cannot* lie for the reason that such forms have two or more faces parallel to a symmetry plane or planes. For reference purposes such a list is given below.

Holohedral isometric — cube and dodecahedron.

Tetrahedral hemihedral isometric — no form. (See statement under definition of a twinning plane on p. 129.)

Pentagonal hemihedral isometric — cube.

Holohedral hexagonal — basal-pinacoid, 1st order prism, and 2nd order prism.

Rhombohedral hemihedral hexagonal — 2nd order prism.

Pyramidal hemihedral hexagonal — basal-pinacoid.

Trigonal hemihedral hexagonal — basal-pinacoid and 2nd order prism.

Trapezohedral tetartohedral — no form.

Holohedral tetragonal — basal-pinacoid, 1st order prism, and 2nd order prism.

Sphenoidal hemihedral tetragonal — no form. (See statement under definition of a twinning plane on p. 129.)

Pyramidal hemihedral tetragonal — basal-pinacoid.

Holohedral orthorhombic — macro-, brachy-, and basal-pinacoid.

Sphenoidal hemihedral orthorhombic — no form.

Holohedral monoclinic — clino-pinacoid.

Holohedral triclinic — no form.

## CHAPTER IX

### MISCELLANEOUS FEATURES

#### **Parallelism of Growth.**

When several crystals which may or may not be in contact with each other have all similar faces parallel, parallelism of growth is said to exist. When such parallel-growing crystals are in contact they may mutually interpenetrate, and are then apt to be confused with twins of interpenetration since they bear a superficial resemblance to such twins, and re-entrant angles are common on both.

Cases of parallelism of growth in which the crystals are not in contact are relatively rare, and are difficult to explain. A good illustration of their occurrence is sometimes exhibited by small but well-formed chalcopyrite crystals dotted over the surface of crystallized sphalerite. More frequently a comparatively large crystal appears to be made up of many smaller ones arranged in parallel positions. This is sometimes splendidly shown by large, rather rough, octahedral crystals of fluorite.

*Parallelism of Growth and Twinning Differentiated:* A group of two or three interpenetrating crystals in parallel position may, as has already been mentioned, be confused with a twin of interpenetration, but may be distinguished therefrom by the fact that it is impossible to find an axis so placed that, if one crystal could be revolved  $180^\circ$  around

it, the rotated crystal would exactly coincide in position with another crystal. As it is not always easy to find the twinning axis, especially in the case of distorted crystals (see p. 144), it will be found easier to base the distinction upon the following facts:

In cases of parallelism of growth, *all* similar faces of all crystals involved will be in parallel positions.

In the case of twins of interpenetration, *some* similar faces of the crystals involved will *not* be in parallel positions although many, perhaps most, such faces may be parallel.

### **Striations.**

*Striations Defined:* Striations are minute terraces or steps, so small that they often appear like lines etched or drawn upon natural crystal faces.

Groups of such lines in parallel positions are not uncommon on natural crystals, and are often of great service in determining the degree of symmetry of the crystal. They are due to three causes, namely: (1) oscillation of two or more crystal faces; (2) oscillatory twinning; and (3) interference of two crystals in contact with each other. Each will be discussed in the order named. Whenever one face meets another of different slope an edge is formed; and, if two such faces alternate with each other, a series of edges parallel to the first result. Frequent alternation of two such faces is known as oscillation, and produces many parallel edges.

*Striations Produced by Oscillation of Faces:* Nature sometimes appears to be uncertain as to which

of two faces or forms she prefers to produce, and, instead of one form being more or less prominently modified by the other, many small faces of each form alternate with each other, and form a series of terraces.

As an illustration, consider a mineral (such as pyrite) on crystals of which the cube and pentagonal dodecahedron are equally apt to occur. The cube has a horizontal face on top of the crystal, while the pentagonal dodecahedron has a face sloping gently down toward the observer; and, if the latter striates the former, the cube face will be interrupted by an indefinite number of tiny steps or terraces running from right to left, of which the horizontal strips represent the cube, while the sloping strips represent the pentagonal dodecahedron. If the width of the latter is very small, the cubic shape of the crystal may not be noticeably changed, yet even then the resulting striations may be very distinct, since no light is reflected from the surfaces belonging to the pentagonal dodecahedron when the cube surfaces reflect light. In a similar fashion a pentagonal dodecahedron may be striated by a cube if there is a strong tendency for the former to predominate over the latter.

Almost any face is capable of striating any other face if the forms involved are in the same division of a system, but, in general, it may be said that those forms which intersect at interfacial angles approaching  $180^\circ$  are much more apt to striate each other than are those whose intersections depart considerably from  $180^\circ$ . In fact, faces intersecting at an angle of  $135^\circ$  rarely striate each other, and faces

intersecting at angles of less than  $135^\circ$  almost never do so.

Such striations always conform strictly to the symmetry of the face on which they are found. That is, a group of striations on one side of a symmetry plane must be balanced perfectly by a similar group on the opposite side of such a plane. It follows from the statements just made that striations produced by oscillation of faces may cross a symmetry plane at right angles to it, and may run parallel to a symmetry plane on both sides of it, but *they can never cross a symmetry plane obliquely*. If the striations on one portion of a crystal face are so disposed as to intersect a symmetry plane obliquely, they must be balanced on the opposite side of the symmetry plane by a similar group of striations which meet the first group at an angle, and which are similarly inclined to the symmetry plane. Fig. 100, which shows a cube face striated by a hexoctahedron, illustrates this law.

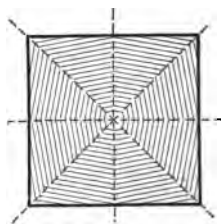


FIG. 100. — Cube face striated by a hexoctahedron. The positions of the symmetry planes are indicated by broken lines.

It is the fact that striations must conform to the symmetry of the crystals on which they occur that makes them of service in determining the symmetry of crystals in cases where the crystal forms present are not distinctive of any particular division of a system. For instance, the cube occurs unchanged in appearance in all divisions of the isometric system, but a cube striated like Fig. 101 must



have a pentagonal hemihedral arrangement of its molecules, since it is evident that the secondary symmetry planes are lacking, while the principal symmetry planes are present. Similarly, Fig. 102 must represent a tetrahedral hemihedral cube, since

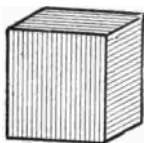


FIG. 101. — Cube striated by a pentagonal dodecahedron.

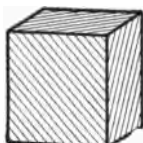


FIG. 102. — Cube striated by a positive tetrahedron.

the secondary symmetry planes are present and the principal symmetry planes are absent.

In order to determine the name of any form striating another form, it is only necessary to ascertain the name of a face which would intersect the striated face in an edge parallel to one of the striations. For instance, it is evident that the pentagonal hemihedral cube shown in Fig. 101 is striated by a face sloping directly toward the observer and parallel to the right and left crystal axis. Such a form is either a dodecahedron or a pentagonal dodecahedron. As a face of the latter form will intersect a cube face in a blunter angle than that formed by the intersection of a dodecahedron and a cube, one is safe in assuming that in the case under consideration the striations are produced by the oscillation of cube and pentagonal dodecahedron faces.

*Striations Produced by Oscillatory Twinning:* If successive twinning planes in an oscillatory twin

are very close together, a series of ridges and depressions or terraces may be formed on some of the faces of a crystal, as illustrated in Fig. 97. When such ridges or terraces are very narrow, they bear a very close resemblance to striations produced by oscillation of faces. In fact, they cannot always be distinguished from such striations, but they may differ therefrom in that twinning striations may cross each other and may produce a cross-hatched appearance, they cannot be parallel to a symmetry plane (excepting in the case of tetrahedral hemihedral isometric and sphenoidal hemihedral tetragonal crystals), and they may cross a symmetry plane obliquely. More important still is the fact that striations produced by oscillation of faces are confined to the surface of a crystal, while striations produced by oscillatory twinning may be shown equally well upon some cleavage faces.

*Striations Produced by Interference:* When two crystals develop in contact with each other the surface between them is sometimes striated in an irregular and peculiar fashion, difficult to describe, but fairly well illustrated by Fig. 103. These striations are usually coarse, and appear to be utterly independent of the symmetry of the crystal.



FIG. 103. — Quartz crystal showing striations produced by interference.

### **Cleavage.**

*Cleavage Defined:* Cleavage is the result of a tendency shown by many crystalline substances to

split more or less easily parallel to one or more possible crystal faces. In some cases this tendency is so well developed that the cleavage surfaces are almost as smooth and highly polished as crystal faces, with which cleavage surfaces are sometimes confused.

If cleavage exists parallel to one face of a given crystal form, it is always possible to develop it parallel to every other face of that same form; and, not infrequently, cleavages parallel to the faces of two different forms may be developed on any one crystal.

Cleavage surfaces may be distinguished ordinarily from crystal faces by the fact that they are not usually perfectly flat, but appear to be covered with or made up from very thin sheets or plates, often with curving edges.

### **Crystal Habit.**

The general shape assumed by a crystal is called its habit. Among the commoner terms descriptive of habits are the following:

1. *The name of some crystal form:* For instance, it may be said that a crystal has an octahedral habit when it has the general shape of an octahedron no matter how many other forms are present, or whether the octahedron itself is actually present or absent.

2. *Tabular habit:* This term may be applied to any crystal having the shape of a tablet — an object with two dimensions much greater than the third.

3. *Prismatic habit:* This term may be applied

to any crystal greatly elongated in any one direction no matter whether that direction be parallel to a prism or not. An *acicular* (needle-like) habit is merely an extreme development of a prismatic habit.

### **Distortion of Crystals.**

Most of the statements already made relative to crystals apply only to those which are geometrically perfect, that is, those completely bounded on all sides with faces which in the case of any one form are identically of the same shape and size, and are equally distant from the center of the crystal. Any departure from this condition is known as distortion, and it is unfortunately true that a great majority of crystals are more or less distorted. Two kinds of distortion are recognized, and these are known, respectively, as (1) mechanical distortion, and (2) crystallographic distortion.

*Mechanical Distortion:* Mechanical distortion is produced by pressure on a completed crystal. This may not only change the molecular arrangement, but it may also tend to flatten a crystal and to bend or warp both it and some or all of the bounding faces. This alters the shape and size of some or all of the faces and their distances from the center of the crystal, and may also warp the faces and *change the angles* which they make with each other.

Although mechanical distortion causes a crystal to depart from all the crystallographic laws already given, this departure is often of so slight a nature as to make it possible to make a fairly accurate guess as to the original appearance of the crystal, and thus to determine the system to which it belongs and the

forms represented upon it. Fortunately this type of distortion is comparatively uncommon.

*Crystallographic Distortion:* Crystallographic distortion may be conceived to be produced by moving

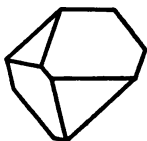


FIG. 104. — Crystallographically distorted octahedron.

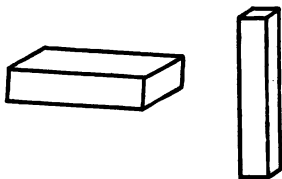


FIG. 105. — Crystallographically distorted cubes.

one or more faces parallel to themselves to any extent either toward or away from the center of the crystal. This may change greatly the shape and size of the faces. In fact, it may result in all the faces of any one form differing from each other in shape and size. Fig. 104 represents such a distorted octahedron, while Fig. 105 represents distorted cubes. In the latter case opposite and parallel faces are of the same shape and size, but differ in these particulars from adjacent faces.

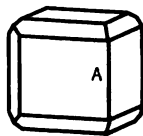


FIG. 106. — Cube modified by a dodecahedron with one face of the latter (which should truncate edge A) suppressed.

Not infrequently a face seems to have been moved outward to such an extent as to have been completely crowded off the crystal. This is illustrated in Fig. 106, and faces thus destroyed are said to be *suppressed*.

Although the shape and size of faces and their distances from the center of the crystal are changed

by crystallographic distortion, it is important to remember that the *angles* which such faces make with each other and with the crystal axes *remain unchanged*, and that the angles between edges are likewise unaltered. This follows from the fact that there is no change in the arrangement of the molecules.

From the statements just made it is evident that the definitions of secondary and principal symmetry planes already given cannot be applied to crystallographically distorted crystals. For these, it is necessary to substitute the following definition of a symmetry plane:

Any plane through a crystal is a symmetry plane if there are approximately the same number of faces on opposite sides of this plane, if most of these faces are arranged in pairs on opposite sides of and equally inclined to this plane, and if any two adjacent faces on one side of this plane are usually balanced on the other side by two adjacent faces making identically the same angle with each other. While this rule is not very rigid, and some mistakes may be made in its application, these will be rare exceptions after the student has studied crystals for some time.

It is fortunately true that crystals subject to crystallographic distortion are apt to occur in groups rather than in isolated individuals, and that some members of such groups are apt to be much less distorted than others. In fact, a little search will usually reveal one or more crystals almost geometrically perfect in development, and it is upon these that the attention should be fixed.

In examining crystallographically distorted crys-

tals, it will be found useful to observe the following two rules: (1) All the faces of any one form on a crystal will be of exactly the same color, luster, and smoothness; and, if any one face is striated, all will be striated and in a similar fashion. (2) Where suppression of faces has occurred it is often impossible to decide whether a form is holohedral or its hemihedral or tetartohedral equivalent, as, for instance, a 1st order pyramid or a rhombohedron. In such cases, always assume that the form under consideration is the one which would necessitate the least suppression of faces.

As an illustration of the latter rule, consider a hexagonal crystal showing a 1st order prism capped with six pyramidal faces in the 1st order position, which may represent either a 1st order pyramid or a + and a - rhombohedron. Suppose that a single face in the position of a 2nd order pyramid is found at one of the corners formed by the intersection of two pyramidal and two prismatic faces. Such a crystal is illustrated in Fig. 107. The pyramidal face in the 2nd order position can evidently be interpreted either as a 2nd

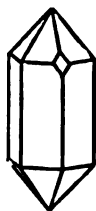


FIG. 107. — Quartz crystal showing suppression of 2nd order trigonal pyramid faces.

order pyramid or a 2nd order trigonal pyramid. If we decide the former to be the correct explanation, we must assume the suppression of eleven faces; while if we incline toward the latter possibility, we need assume the suppression of but five faces. According to the rule just laid down, we should

make the second assumption, and call the form a 2nd order trigonal pyramid, making the crystal trapezohedral tetartohedral.

In conclusion, it should be remembered that a majority of crystals are not bounded by faces on all sides, but are attached to some foreign substance or to other crystals. This means that a considerable proportion of the surface of most crystals will not bear crystal faces. Such crystals can hardly be called distorted, but the condition mentioned naturally adds to the difficulties involved in their classification.

#### **Vicinal Forms.**

The law of rationality of parameters already given states that parameters are always *rational*, fractional or whole, *small* or infinite numbers. While this law holds for all the more prominent faces on crystals that are not mechanically distorted, there sometimes occur on such faces rather inconspicuous elevations, often curved, which accord in form with the symmetry of the face on which they are found, but which are made up of faces that have parameters which are either large, irrational, or both large and irrational. Forms possessing such parameters are termed vicinal. Their cause is not understood. They may be ignored unless unusually prominent, but their form and distribution are sometimes of service in determining the degree of symmetry of crystals.

#### **Etched Figures and Corrosion.**

Natural solutions sometimes attack or corrode the plane surfaces bounding crystals. When this hap-



pens the edges may be rounded and the faces curved, and some or all faces may show small triangular, quadrilateral, or polygonal, flat-faced depressions or pits called etched figures. These differ in shape on crystals of different minerals and even on the faces of different forms on an individual crystal. In fact, one form on a crystal may show well-developed etched figures while others are unattacked or merely smoothly corroded. In all cases, however, the shape of the etched figures accords with the symmetry of the face on which they occur, and a study of such figures will sometimes prove helpful in determining the degree of symmetry of crystals showing them.

# SYSTEMS, DIVISION OF SYSTEMS, AND FORMS TABULATED

## Isometric System

### *Holohedral Forms*

Octahedron  
Trisoctahedron  
Dodecahedron  
Trapezohedron  
Hexahedron (cube)  
Hexoctahedron  
Tetrahexahedron

Dodecahedron  
Hexahedron (cube)  
Trapezohedron  
Trisoctahedron

### *Gyroidal Hemihedral Forms*

Pentagonal Icositetrahe-  
dron

### *Tetrahedral Hemihedral Forms*

±Tetrahedron  
±Trigonal Tristetrahedron  
±Tetragonal Tristetrahe-  
dron  
±Hextetrahedron

Octahedron  
Trisoctahedron  
Dodecahedron  
Trapezohedron  
Hexahedron (cube)  
Tetrahexahedron

-----  
Hexahedron (cube)  
Dodecahedron  
Tetrahexahedron

### *Pentagonal Tetartohedral Forms*

Tetartoid

### *Pentagonal Hemihedral Forms*

Pentagonal Dodecahedron  
Diploid  
-----  
Octahedron

-----  
Octahedron  
Trisoctahedron  
Dodecahedron  
Trapezohedron  
Hexahedron (cube)  
Tetrahexahedron

**Hexagonal System**

*Holohedral Forms*

1st Order Pyramid  
1st Order Prism  
2nd Order Pyramid  
2nd Order Prism  
Dihexagonal Pyramid  
Dihexagonal Prism  
Basal-pinacoid

*Rhombohedral Hemihedral Forms*

±Rhombohedron  
Hexagonal Scalenohedron

-----  
1st Order Prism  
2nd Order Pyramid  
2nd Order Prism  
Dihexagonal Prism  
Basal-pinacoid

*Pyramidal Hemihedral Forms*

3rd Order Pyramid  
3rd Order Prism

-----  
1st Order Pyramid  
1st Order Prism  
2nd Order Pyramid  
2nd Order Prism  
Basal-pinacoid

*Trigonal Hemihedral Forms*

±1st Order Trigonal Pyramid  
±1st Order Trigonal Prism  
Ditrigonal Pyramid  
Ditrigonal Prism

2nd Order Pyramid  
2nd Order Prism  
Basal-pinacoid

*Trapezohedral Hemihedral Forms*

Hexagonal Trapezohedron  
-----  
1st Order Pyramid  
1st Order Prism  
2nd Order Pyramid  
2nd Order Prism  
Dihexagonal Prism  
Basal-pinacoid

*Trapezohedral Tetartohedral Forms*

±Rhombohedron  
±2nd Order Trigonal Pyramid  
±2nd Order Trigonal Prism  
Trigonal Trapezohedron  
Ditrigonal Prism

-----  
1st Order Prism  
Basal-pinacoid

*Rhombohedral Tetartohedral Forms*

1st Order Rhombohedron  
2nd Order Rhombohedron  
3rd Order Rhombohedron  
3rd Order Prism

-----  
1st Order Prism  
2nd Order Prism  
Basal-pinacoid

**Tetragonal System***Holohedral Forms*

1st Order Pyramid  
 1st Order Prism  
 2nd Order Pyramid  
 2nd Order Prism  
 Ditetragonal Pyramid  
 Ditetragonal Prism  
 Basal-pinacoid

2nd Order Pyramid  
 2nd Order Prism  
 Ditetragonal Prism  
 Basal-pinacoid

*Pyramidal Hemihedral Forms*

3rd Order Pyramid  
 3rd Order Prism

*Sphenoidal Hemihedral Forms*

±Tetragonal Sphenoid  
 ±Tetragonal Scalenohedron

-----  
 1st Order Pyramid  
 1st Order Prism  
 2nd Order Pyramid  
 2nd Order Prism  
 Basal-pinacoid

-----  
 1st Order Prism

**Orthorhombic System***Holohedral Forms*

Pyramid  
 Prism  
 Macro-dome  
 Brachy-dome  
 Macro-pinacoid  
 Brachy-pinacoid  
 Basal-pinacoid

*Sphenoidal Hemihedral Forms*

Orthorhombic Sphenoid  
 -----  
 Prism  
 Macro-dome  
 Brachy-dome  
 Macro-pinacoid  
 Brachy-pinacoid  
 Basal-pinacoid

**Monoclinic System***Holohedral Forms*

±Pyramid  
 Prism  
 Clino-dome

Ortho-pinacoid  
 ±Ortho-dome  
 Basal-pinacoid  
 Clino-pinacoid

**Triclinic System***Holohedral Forms*

Same as in the orthorhombic system

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